REPORTS OF EXPERIMENTS

ON THE

PROPERTIES OF METALS FOR CANNON,

AND THE

QUALITIES OF CANNON POWDER;

WITH AN

ACCOUNT OF THE FABRICATION AND TRIAL OF A 15-INCH GUN.

BY

Thomas Jefferson

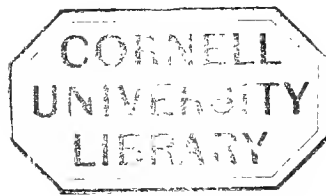## CAPT. T. J. RODMAN,

OF THE ORDNANCE DEPARTMENT, U. S. ARMY.

By Authority of the Secretary of War.

BOSTON, MASS.:

CHARLES H. CROSBY.

1861.

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PREFACE.

THE following Reports might have been considerably abridged, and their contents rendered less repulsive to the general reader by re-writing them after the experiments had all been completed; but for the use of the practical student, it was deemed preferable to publish the Reports as they were originally made.

In these Reports I have endeavored, in every case, to record results exactly as they were evolved by experiment, accompanying them by such explanatory remarks as appeared necessary to a clear understanding of the circumstances under which they were evolved.

Few, if any, of the subjects experimented upon are regarded as exhausted, the experiments having in most cases only contracted the limits of uncertainty, without having arrived at absolute truth.

My letter to the Colonel of Ordnance, (p. 93,) is re-published, reference to it having been found necessary in writing these Reports.

T. J. RODMAN,
Capt. of Ordnance.

APRIL 17, 1861.

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OF

EXPERIMENTS

MADE FOR THE PURPOSE OF FURTHER TESTING

THE

RELATIVE MERITS

OF

CAPTAIN RODMAN'S

MODE OF COOLING CANNON, AS COMPARED WITH THE ORDINARY METHOD.

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REPORT

OF

EXPERIMENTS MADE FOR THE PURPOSE OF FURTHER TESTING THE RELATIVE MERITS OF CAPT. RODMAN'S MODE OF COOLING CANNON, AS COMPARED WITH THE ORDINARY METHOD.

IN undertaking these experiments, the first object to be attained was to procure iron of a suitable quality for casting into guns of the size of those to be made.

With a view to the attainment of this object, the following preliminary trials were made :—

PRELIMINARY TRIALS.

July 18th, 1856, three tons of No. 2 Greenwood pigs were melted in an air furnace with bituminous coal, and run into 5-inch square pigs, dry sand moulds. July 19th, forty-five hundred of the above 2d fusion pigs, and fifteen hundred of No. 2 Springfield pigs, were melted together, and a cylinder, 20 inches diameter, and 24 inches high, was cast from it in a dry sand mould. Two specimens were taken from the lower end of this cylinder, one 3 inches, and the other 7 inches from the axis. The first gave Density = 7.273, and Tenacity = 42.884. The second gave Density = 7.272, and Tenacity = 38.993. These tests were of the highest order, both for density and tenacity; but the metal appeared to be stubborn, harsh, and inclined to brittleness, and gave evidence of a strong tendency to separation into different compounds of carbon and iron, collections of free graphite being quite conspicuous on the fractured surface; and, as it was known that this tendency would be increased, and its effects more fully developed, by the slower rate of cooling to which the iron would be subjected in the larger masses of the guns, it was rejected;

and, on the 12th of August, 3000 of 2d fusion No. 2 Greenwood pigs, and 1500 of No. 3 Greenwood pigs, were melted together, with 1500 2d fusion No. 1 Salisbury pigs. A portion of this heat was run into a cylindrical mould of dry sand, 20 inch diameter by 24 inch high, cut longitudinally into four parts, by thin cores, thus:—
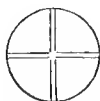
From this cylinder two specimens were taken; one from the centre of the lower end of one of the quarters, axis parallel to that of the cylinder; the other from the middle of the length of same quarter, equi-distant between axis and exterior of the cylinder, its axis being perpendicular to the face of the quarter from which it was taken, and parallel to a tangent to its circumference. The first of these specimens gave Density $= 7.137$; Tenacity $= 33.268$. The other gave Density $= 7.159$; Tenacity $= 36.373$.

These tenacities were considered quite satisfactory, though the densities were rather low; but it was thought that this quality, as well as the tenacity, would be improved by bringing the iron up a little higher, and that the metal would not be rendered brittle by so doing, as there was scarcely any appearance of mottle in the fracture, and the iron appeared to be very tough.

Accordingly, a sufficient quantity of No. 2 Greenwood pigs, and of No. 1 Salisbury pigs, were re-melted, and prepared for casting the guns, samples being taken from one of the 5-inch square pigs, into which each heat was run. Preliminary samples are all marked, 1st, A, and then by numbers and letters, to designate the number of heat, and other characters of the specimens.

TABLE *showing Mechanical Tests of Preliminary Castings.*

Marks.	Description.	Density.	Tenacity.
A. 1 B,	From small bars, cast from No. 2 Greenwood pigs, . . .	7.184	33079
A. 1 B. D,	Duplicate of A. 1 B, ...	7.198	31384
A. 2 B,	From small bars cast from 2d heat, 3 parts 2d fusion, No. 2 Greenwood, and 1 part No. 2 Springfield pigs, . . .	7.307	35486
A. 3 P,	From 5-inch square pig, made from No. 2 Greenwood pigs, .	7.099	23776
A. 2 P,	From 5-inch square pig, made from 3 parts 2d fusion Greenwood No. 2 pigs, and 1 part Springfield No. 2 pigs, . . .	7.304	31317
A. 1 c. 3,	From cylinder 20 inches diameter and 24 inches high, made from 3 parts 2d fusion Greenwood No. 2 pigs, and 1 part No. 2 Springfield pigs, taken from bottom, 3 inches from axis, .	7.273	42884
A. 1 c. 7,	From same cylinder as A. 1 c. 3, but 7 inches from axis, . .	7.272	38993
A. 3 B,	From small bar made from No. 1 Salisbury pig, . . .	7.219	25372
A. 4 P,	From 5-inch square pig, made from No. 1 Salisbury pig, . .	7.210	22547
A. 5 P,	From 5-inch square pig, made from 2 parts 2d fusion Greenwood pig, 1 part No. 3 Greenwood pig, and 1 part 2d fusion No. 1 Salisbury pig, ...	7.172	28518
A. 2 C, c.	From central part of large cylinder, 20 inches diameter and 2½ inches high, made from same iron as A. 5 P, axis of specimen as perpendicular to that of cylinder, and parallel to tangent to its circumference, ...	7.159	36373
A. 2 c,	From end of same cylinder A. 2 C, axis parallel to that of cylinder, ... c	7.137	33268
A. 6 P,	From 5-inch square pig, made from 2 parts No. 2 Greenwood pig, and 1 part No. 1 Salisbury pig, ...	7.106	22290
A. 7 P,	From 5-inch square pig, made from 3 parts No. 2 Greenwood pig, and 1 part No. 1 Salisbury pig, ...	7.100	22179
A. 8 P,	From 5-inch square pig, made from 3 parts Greenwood No. 2 pig, and 1 part No. 1 Salisbury pig, ...	7.109	22888
A. 3 c,	From 10-inch cylinder, made from No. 1 Salisbury pig, axis parallel to that of the cylinder, ...	7.191	23873

August 21. The mould for the solid gun was made and placed in the drying oven, and the first coat of clay put upon the core barrel for the hollow gun.

August 22. The mould for the hollow gun was made and placed in the drying oven, and that for the solid gun pitted, and the metal for casting the guns charged as follows, viz:—

Furnace No. 1 received . . . . . 12000 lbs.

Furnace No. 2 received . . . . . 16000 "

Furnace No. 3 received . . . . . 18000 "

Total charge for both guns, ... 46000 lbs.

Seven-ninths of the whole charge was Greenwood iron, and two-ninths Salisbury iron.

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The Greenwood iron consisted of the following varieties, viz :—

 5722 lbs. 2d fusion, No. 2 pigs.

 5085 lbs. 2d fusion, No. 2 pigs, melted with No. 1 Salisbury, in the proportion of 2 parts Greenwood to 1 part of Salisbury.

12372 lbs. 2d fusion, No. 2 pigs, melted with No. 1 Salisbury pig, in the proportion of 3 Greenwood to 1 Salisbury.

 4429 lbs. 3d fusion No. 2 pigs, melted with 1476 lbs. No. 1 Salisbury pigs.

 8172 lbs. No. 3 Greenwood pigs.

35780 lbs. Total Greenwood iron.

 2077 lbs. 2d fusion No. 1 Salisbury pig.

 2543 lbs. 2d fusion No. 1 Salisbury pig, melted with No. 2 Greenwood pigs, in the proportion of 1 part of Salisbury to 2 parts Greenwood.

 4124 lbs. 2d fusion No. 1 Salisbury, melted with No. 2 Greenwood, in the proportion of 1 of Salisbury to 3 of Greenwood.

 1476 lbs. 3d fusion No. 1 Salisbury, melted with 2d fusion No. 2 Greenwood, in the proportion of 1 Salisbury to 3 of Greenwood.

10220 lbs. Total of Salisbury iron.

46000 lbs. Total charge.

The Greenwood iron in these guns was made from magnetic ore, smelted in a furnace of eleven feet diameter of boshes, with charcoal and a warm blast, the temperature of the blast being kept regularly at about 300° Fahrenheit, and at a very low pressure, — say $\frac{3}{8}$ inch of Mercury.

The Salisbury iron was made from brown hæmatite ore, smelted in a furnace of nine (9) feet diameter of boshes, and 30 feet high, with charcoal and warm blast; temperature of blast 450° Fahrenheit; pressure of blast not known.

Blast enters the furnace at two tweyers, the average yield of the furnace being five tons per day. The different kinds of iron were distributed among the three furnaces in the same proportions, so that each one would contain the same composition of iron.

The preliminary melting was all done in one of the furnaces in which the metal for casting the guns was melted. These furnaces are all what are

PLATE 1.

Scale of Feet.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

$\frac{1}{60}$th Size
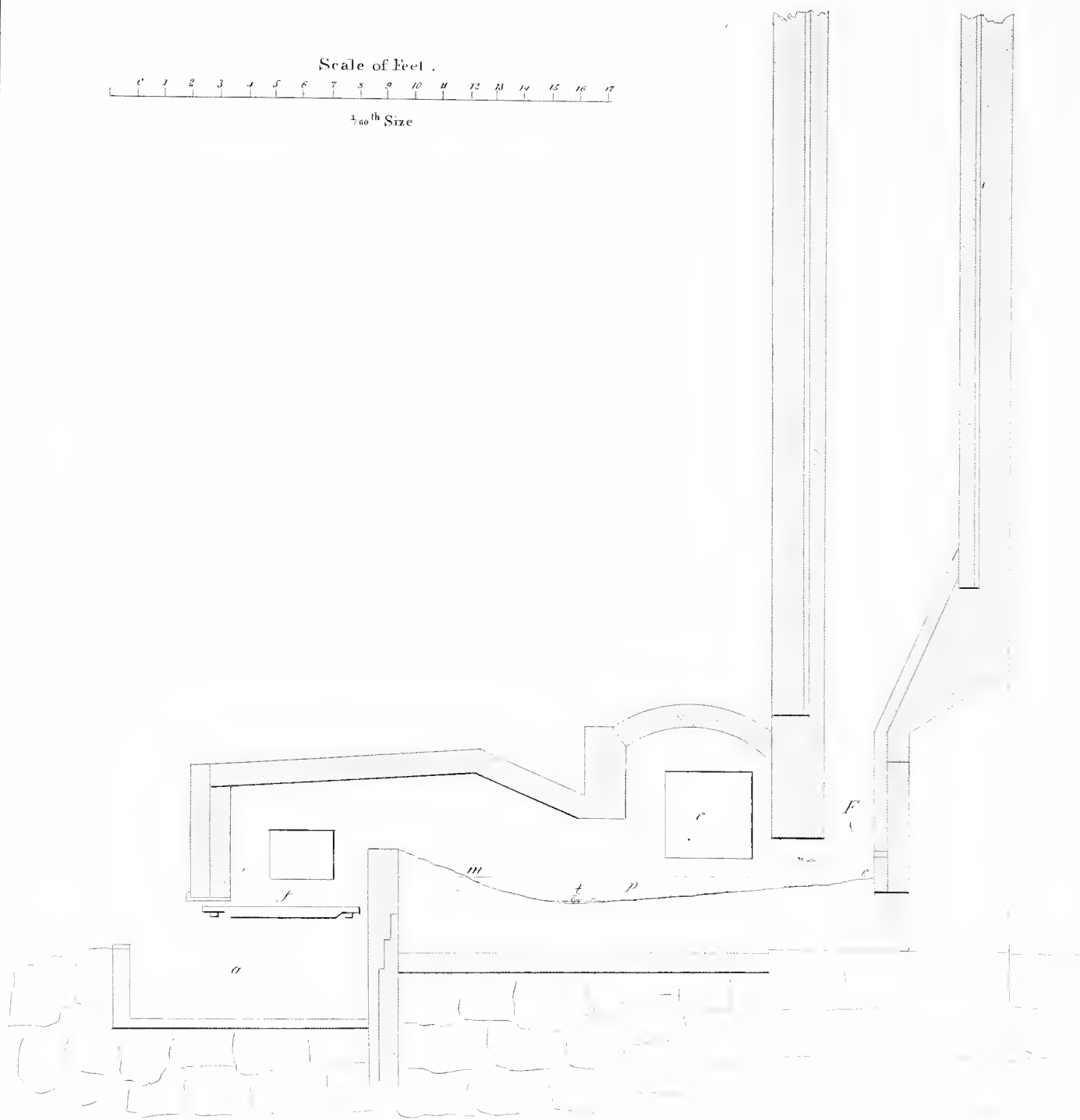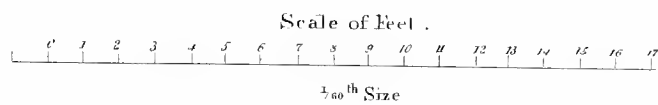
termed air furnaces, having a sufficient height of chimney to create the requisite velocity of air through the fuel; which in all the meltings, both preliminary and for the guns, was bituminous coal of the best quality.

The furnaces are so constructed that the metal, as it melts, flows towards the flame.

The accompanying drawing (Plate 1,) shows a vertical longitudinal section of one of the furnaces, in which (*a*) is the ash-pit, (*f*) fuel chamber, (*p*) metal pool, (*t*) tap hole, (*c*) charging door, and (*F*) the flue.

With a given charge of metal its treatment may be somewhat varied by the manner of dressing the bottom of the furnace, a broad, shallow pool exposing the iron more effectually to the action of the flame, and consequently making it *hotter* than when it is collected in a deep pool, with a small surface exposed to the flame.

The drawing represents the furnace as dressed for melting the iron from which the guns were cast; the line (*m e*) showing the surface of the metal when melted. The mean depth of the metal was about seven inches; that in No. 3 being something less, it being desirable that the iron in this furnace should be very hot, as it had a considerable distance to run — greater than that of either of the other furnaces. Furnaces Nos. 1 and 2 were charged up to their capacity. No. 3 could have received, perhaps, two tons more.

The flasks in which these guns were cast are in two parts, which open longitudinally, one-half of the gun, and one trunnion, being moulded in each half of the flask.

Their cross section, when clamped together ready to receive the metal, is hexagonal, which gives an unequal thickness of sand around different parts of the same section of the gun, which, it is believed, is calculated to produce irregularity in the rate of cooling, of the different wedges or staves of which the gun may be supposed to consist. And, as perfect homogeneity, in each of the concentric cylinders of which the gun may be supposed to consist, is believed to be of the utmost importance to its endurance, it would seem that a flask of circular cross sections, which would give a uniform thickness of sand around every part of the same cross section of the gun, would be more suitable for casting cannon.

The casting for the hollow gun was cylindrical from about the middle of the chase to the muzzle, while that for the solid gun corresponded more nearly in shape with the finished gun.

Casting.

August 23, 1856.   Two 10-inch Columbiads were cast from the metal charged on the 22d.   One, No. 331, was cast hollow, and cooled from the interior by circulating water through the core barrel; and the other, No. 332, was cast solid, and cooled from the exterior

The furnaces were lighted at 10h. 50m. A. M., and Nos. 1 and 3 were tapped at 3h. 20m. P. M., the metal in all the furnaces having been 30 minutes in fusion.   After the flow of metal from these furnaces had sufficiently decreased to admit of so doing, No. 2 was tapped, and the flow of metal kept nearly uniform during the whole time of casting.

The metal from all the furnaces was received into one reservoir, from which it flowed in a single stream to a point equi-distant from the two gun moulds; from this point it reached the mould for the solid gun in a single stream, and that for the hollow gun in two streams, one entering the mouth of the mould on each side of the core, the metal in both cases entering the mould directly, and not through "side runners."   The hollow gun mould was filled in 8½ minutes, and that for the solid gun in 12 minutes; the great heat of the metal preventing the workmen from so regulating its flow as to fill both moulds simultaneously.

Condition of Pits.

Both pits were closely covered at the time of casting; that in which the hollow gun was cast was a new pit with an earthen bottom, recently walled up, and in which no castings had yet been made.   On this account this pit had fire kindled in it on the evening previous to the day of casting, and had been previously dried, to some extent, by fire.   The pit in which the solid gun was cast was an old one, with a wrought iron bottom, and in which heavy castings had been recently made.

The pits were both in good order for casting, and well adapted to slow cooling; both being provided with means for keeping up a hot fire around the flasks, for as long a time as might be desired.

Fire was lighted in the pit of the solid gun at 3h. 55m. P. M.   Temperature of hollow gun pit at the same time, 415°.

Cooling.

Water circulated through the core barrel of the hollow gun at the rate of two cubic feet per minute; entered at 71°, and left at 111°.

Temperature of Pits, at the undermentioned numbers of hours after casting, in Fahrenheit degrees.

Hours after casting.	TEMPERATURE.		Remarks.
	331	332	
	Hollow.	Solid.	
0,	415°	80°	
2,	500	300	
4,	—	350	
17,	530	530	
25,	550	600	Thermometer broke; temperature judged of.
40,	550	600	" " " "
48,	1000	900	{ Lower part of flasks at a dull red heat, and the fire was allowed to gradually burn out from this time.
64,	300	350	
88,	175	200	
94,	240	300	Temperature taken by the thermometer, and indicates that
115,	150	150	the temperature of pits, from 48 to 88 hours after casting,
119,	120	190	must have been higher than that adjudged and recorded.
207,	84	144	

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TABLE *showing the change of temperature, in Fahrenheit degrees, produced on water while circulating through the core barrel at the rate of two cubit feet per minute, at the undermentioned times after casting.*

Hours.	Change.	Hours.	Change.	Hours.	Change.	Hours.	Change.	Hours.	Change.
1	40°	20	43°	53	12°	72	7½°	104	3°
2	39	21	40	54	12	73	7½	110	3
3	34	22	38	55	12	74	7	140	2
4	32	23	34	56	11½	75	7	157	1
5	29	24	32	57	11½	76	6½	207	0
6	26½	25	30	58	11	77	6½		—
7	24½	26	28	59	10½	78	6½		—
8	22½	27	24	60	10	79	6½		—
9	21	28	23	61	9½	80	6		—
10	19½	29	22	62	8½	81	5½		—
11	18½	30	20	63	8	82	5½		—
12	18	31	19	64	7	83	5		—
13	17½	32	18	65	7	84	4½		—
14	17	33	17	66	7	85	4½		—
15	17	34	16	67	7	86	4½		—
16	16	35	15	68	6½	87	4½		—
*17	61	36	14½	69	6	88	4		—
18	56	37	14	70	7½	89	3½		—
19	49	38	13	71	7½	95	3½		—
	558		460½		172		106		9

* Core barrel removed, and water circulated through cavity left.

At seventeen hours after casting, the core barrel was removed from the hollow gun, and water at the rate of two cubic feet per minute circulated through the cavity thus left, until the casting was entirely cold.

This was accomplished without allowing the water to wet the exterior of the gun, by casting a wrought iron tube into the gun head, so as to enter the cavity left by the core barrel at about 12 inches from the upper end of the casting. The water, on reaching this height, flowed out through the tube to a sewer, by which it was conveyed out of the foundry.

From inspection of the cooling table, it appears that the water left at the same temperature from the 38th to the 53d hour after casting; the casting could not, therefore, have cooled any during this time, the fire in the pit supplying as much heat at the exterior as the water carried off from the interior.

The gun should not have remained so long at a constant temperature, as it was subjecting it to an annealing process, by which, I have no doubt, that both

its specific gravity and tenacity were diminished. Nor was it so intended; but the watchman who attended the pits during the night had accumulated such a body of coal around the flask, that the temperature could not be controlled.

The tables showing the temperature of the pits, show that, during the time referred to, the highest temperature of the flask was a dull red heat; and the gun must have been at a lower temperature as the heat passed from the exterior to the interior.

Taking the sum of the changes of temperature from the time of casting till the change became constant, or to the 38th hour, we have 1018°; this, multiplied by the weight of water which passed through the core barrel in one hour, viz., 120 cubic feet, gives 7.635.000. The number of degrees which the heat carried off would raise one pound of water.

Major Wade finds, (Reports of Experiments on Metal for Cannon, page 303,) that one pound of iron at the ordinary temperature of casting, will raise one pound of water 455°; in cooling to 105°; — 7.635.000 divided by 455° will therefore give the number of pounds of iron, which the heat carried off by the water, would raise from 105° to casting temperature. This quotient is 16.780. The weight of the casting was about 20.000 pounds; it therefore appears that about three-fourths of the total heat was carried off from the interior, and one-fourth from the exterior.

The hollow gun was removed from the pit and flask, at 10 A. M., September 1st; the solid one was removed from the pit and flask September 5th. Temperature of the gun on leaving the flask, 90° to 100°.

This gun, though moulded on the same pattern, and by the same men, was found to be full 25 inches larger in diameter than the hollow one. This difference would therefore seem to be due to the greater contraction of the hollow gun, caused by its more rapid rate of cooling.

The diameter of the bore *cast* in the hollow gun was nine (9) inches, allowing half an inch all round for reaming out. On placing this gun in the lathe, the axis of the *cast bore* was found not to coincide exactly with that of the gun; there was, on this account, about three-eighths of an inch more metal reamed out on one side of the cast bore than on the other.

And, should this mode of cooling be adopted, the gun should always be cast a little above size, in order to admit of being finished by the interior, or so that the axis of the *cast* bore shall coincide with that of the finished gun.

These guns both turned very kindly, the chips or turnings being very tough and elastic; those from the hollow gun possessing this quality in a higher degree than those from the solid one, the iron in the latter being much coarser grained, less compact, and softer than that in the hollow gun.

The amount of uncombined carbon appeared to be greater in the solid than in the hollow gun, and I have little doubt that such was the case; since, as I believe, the whole amount of carbon is chemically combined with the iron when in fusion, and the slower the rate of cooling, the greater will be the proportion of that compound of carbon and iron most prone to be formed, viz., graphite. The fact that the same iron may be rendered perfectly white and hard, or gray and soft, (the first by casting in iron moulds, and in small masses, where the rate of cooling is very rapid, and the other by casting in large masses, and cooling slowly,) goes far to sustain this view of the subject.

I have not had the means of analyzing the iron of these guns; but it would be interesting and instructive to *know* whether or not the different rates of cooling have affected the chemical character of the iron.

On turning off the exterior of the hollow gun, some small cavities made their appearance just in the neck of the gun. They were at first thought to be sand holes, caused by a small portion of the bottom of the mould having been cut away by the first portion of the metal that entered; but the estimate of the quantity of heat extracted from the interior of the gun, as compared with that which must have escaped from the exterior, renders it more probable that these cavities were situated in the dividing cylinder, which was last to cool.

The vents were bored in a plane perpendicular to the axis of the gun, at the junction of the hemisphere and cylinder of the chamber; the exterior being 6 inches, and the interior 3 inches to the left of a plane containing the axis of the bore, and perpendicular to that of the trunnions.

Inspection.

The guns were accurately measured in all their parts, and were within the prescribed limits of variation in all important points. The ratchets were finished to their proper depths, but were not accurately dressed to the prescribed width; the cascables were not accurately finished, nor the metal around the rimbases chipped off, nor were the sight fields finished. These parts not affecting the durability of the guns, it was not deemed necessary

PLATE II

10 Inch Columbiad Solid Nº 332.

Fig. 1
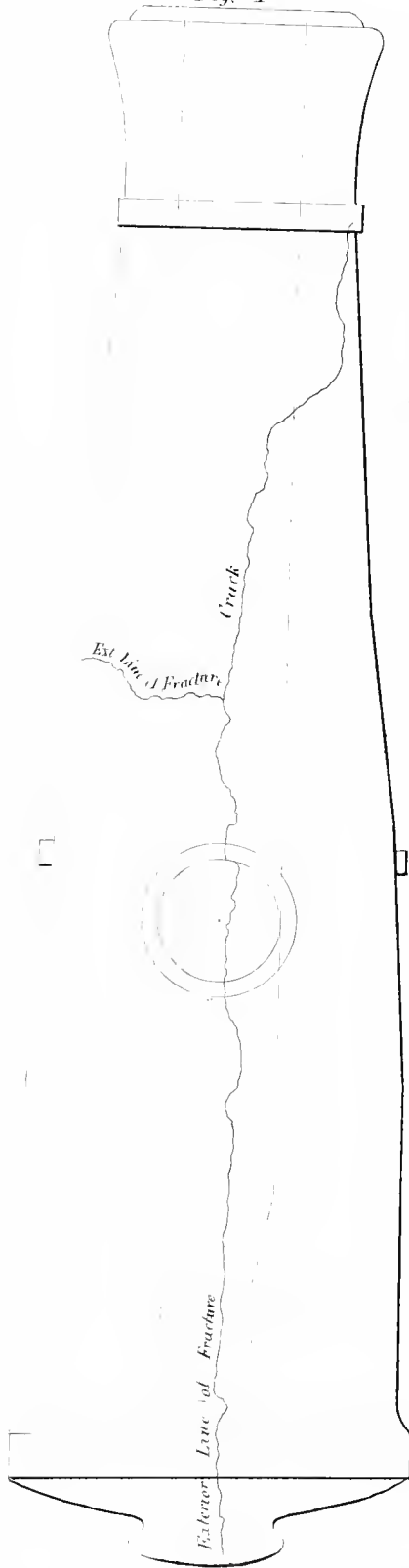
Fig. 2
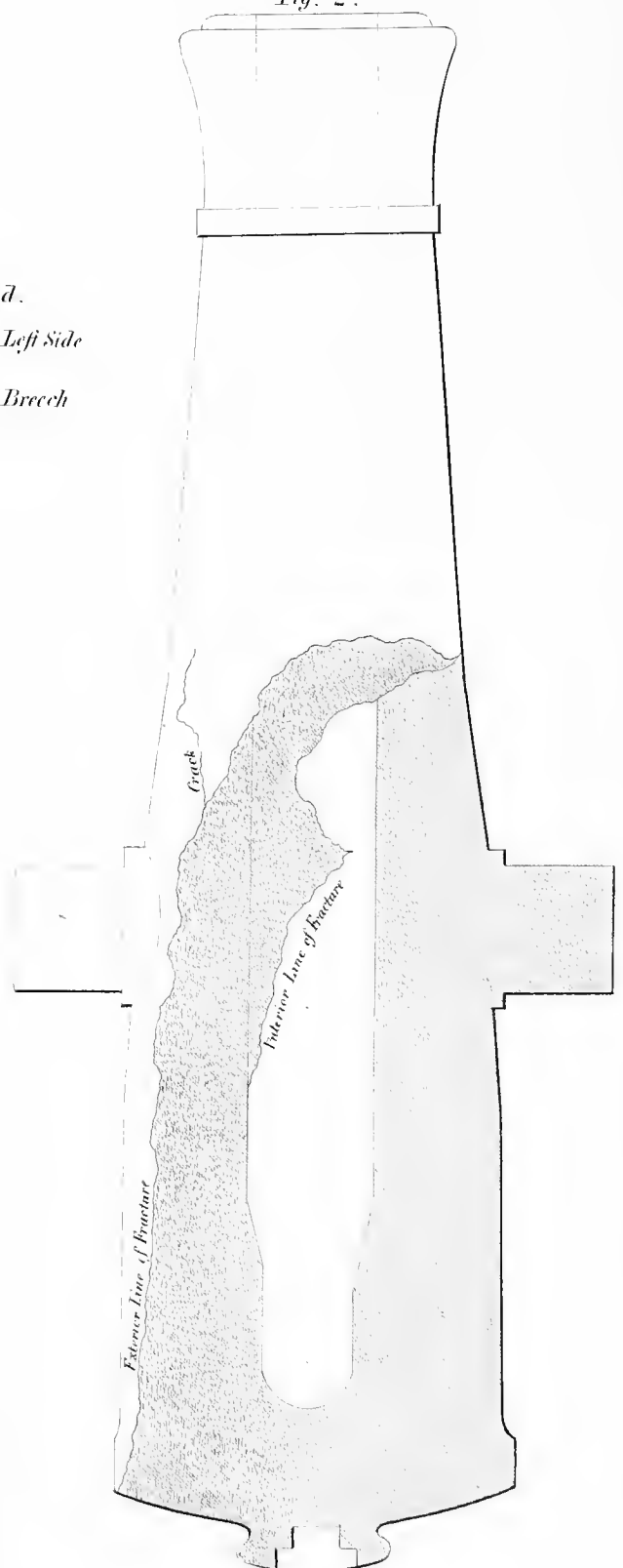
Legend.

Fig 1. Elevation of Left Side
Fig 2. Plan.
Fig 3. Elevation of Breech

Crack

Ext Line of Fracture

Exterior Line of Fracture

Crack

Exterior Line of Fracture

Interior Line of Fracture

Top.

Fig 3.
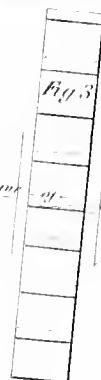
Exterior Line of Fracture

that they should be accurately finished, as the guns were intended to be broken.

Proof.

October 7th, 1856. Both guns were laid on the ground and proved in the ordinary mode.

1st fire, 20 pounds powder (proof range 314 yards), 1 shot (125 lbs.), 1 sabot, and 1 10-inch wad.

2d fire, 24 pounds powder (proof range 314 yards), 1 sabot and 1 shell, 99½ pounds.

The guns were then suspended, each in its own frame, for extreme proof, and fired alternately, with charges of 18 pounds of powder, and one solid shot and sabot; average weight of shot, 125 pounds.

The guns were fired with friction tubes, the shot passing through a pen filled with earth, and lodging in the face of a vertical hill beyond, or more generally rolling down, and being found behind the pen; were recovered and used again till broken, only 8 shots being used in the extreme proof of this pair of guns.

Endurance.

October 9th. The solid gun No. 332 burst at the 26th fire, including proof charges, into two main pieces. The plane of fracture was nearly horizontal, and about one inch below the axis of the gun, passing through the left trunnion. The lower and smaller piece broke off midway between the trunnions and neck, a crack extending forward in the larger piece to the middle of the neck ring. Several longitudinal cracks were found in the chamber and taper, but none in the cylinder of the bore.

Figures 1, 2 and 3, Plate No. 2, show the lines of fracture very accurately.

The firing was continued with the hollow cast gun, the same charges of powder and shot being used up to the 103d fire, including proof charges, when five rounds were fired with the same charge of powder, but a shell of 101.75 pounds, instead of a shot, for the purpose of determining the initial velocity of shells from this calibre of gun. One shell broke in the gun. The firing was then continued with the same charges as before, with solid shot, up to the 213th fire, when a crack was observed, beginning about midway of the taper, and extending into the chamber. After the 270th fire another crack was discovered on the opposite side of the chamber, beginning

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nearer the junction of the taper and chamber than the other, and extending to near the bottom of the chamber.

The shot recovered after the 214th fire was found to be cracked, and marked on opposite sides by a smooth, bright band, indicating that it had rubbed hard against the bore of the gun.

This gun broke at the 315th fire, including proof charges, into three main pieces, splitting through the breech in a nearly horizontal plane ; the lines of rupture running forward, above the right and below the left trunnion, giving a slightly warped surface of fracture, to a point about 12 inches in rear of the neck ring, where the breech pieces broke off from the muzzle piece, leaving it hanging in the suspenders.

One of the breech pieces was thrown to a very considerable height, and fell but a short distance from the intended bomb and fragment proof chamber ; and it is believed to be lucky for those in it at the time, that it did not fall on it. This remark is intended for the benefit of those who may hereafter be engaged in similar experiments.

Figures 1, 2 and 3, Plate No. 3, give an accurate view of the lines of rupture of this gun.

The annexed tables show the enlargement of the bores, chambers, and vents of these guns ; also the mechanical tests of the metal of which they were composed.

Inspection after rupture of the interior of gun No. 331, showed great numbers of small cracks in the chamber, more resembling in appearance a piece of netting than anything else, with occasional larger longitudinal cracks, no cracks of any kind being discoverable in any part of the bore.

Nor did the fractured surfaces exhibit any cavities or appearance of unsoundness in the metal, except the appearance of a slight draw or "soakage" in the chase ends of the fracture of the breech pieces from the muzzle ; these were at the same distance from the surface of the bore as the cavities before mentioned, and doubtless are attributable to the same cause.

From the nature of the fracture of both these guns, it was quite evident that they first gave way by splitting through the breech, the gas afterwards acting as a wedge to extend the fracture forward ; and this has been the case in every Columbiad I have ever seen broken, and indicates the breech as the weak point in these guns.

PLATE III

10 Inch Columbiad Hollow Nº 331.
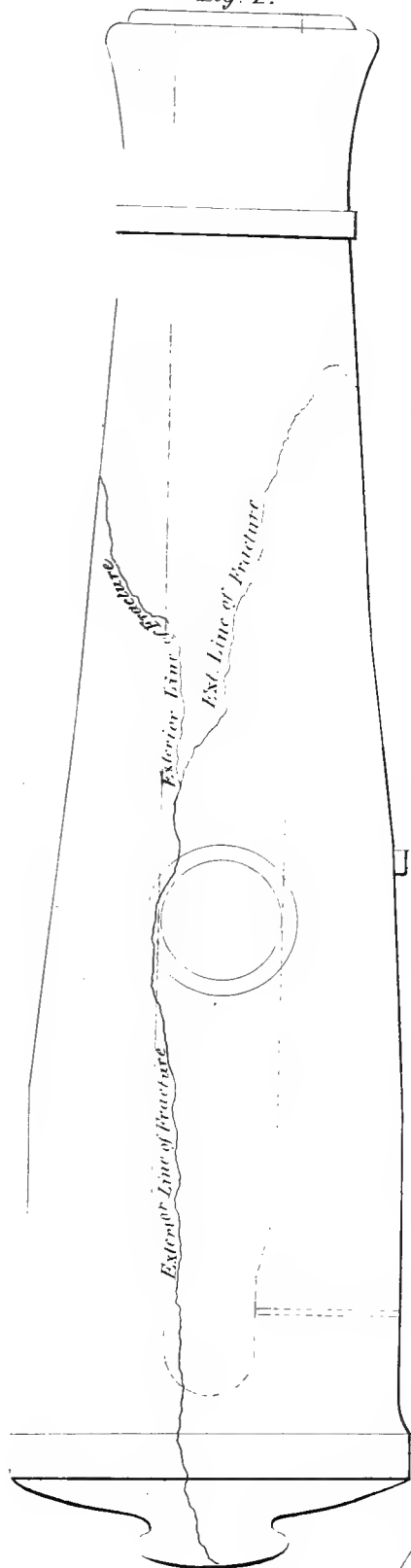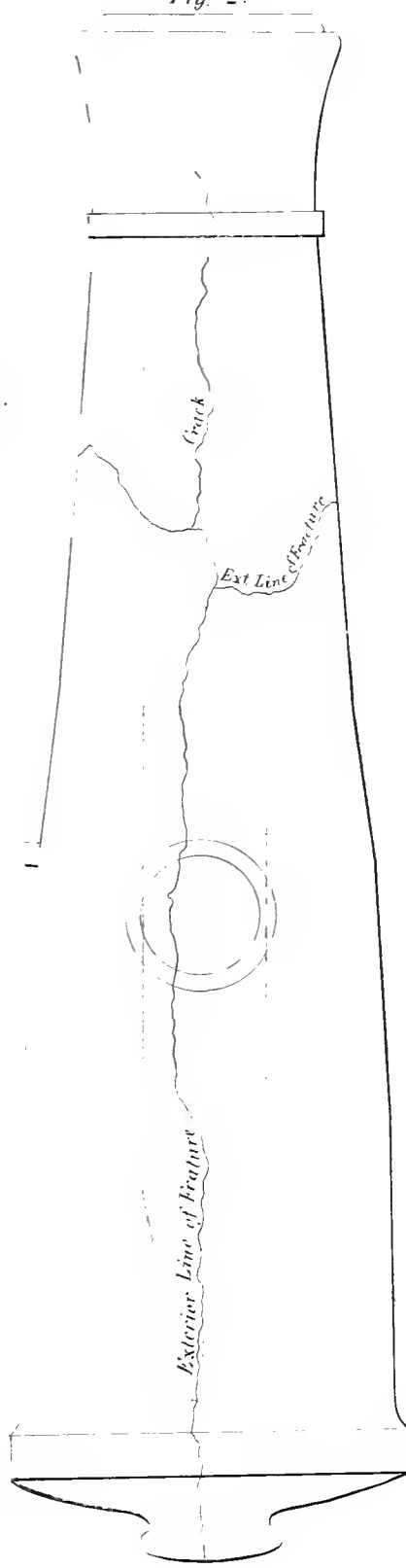
Fig. 1.

Fig. 2.

Legend.

Fig. 1. Elevation of Left Side.
Fig. 2. Elevation on Right Side.
Fig. 3. Elevation of Breech.

Exterior Line of Fracture

Ext. Line of Fracture

Crack

Ext Line of Fracture

Exterior Line of Fracture

Exterior Line of Fracture

Top.

Fig 3

Ext Line of Fracture
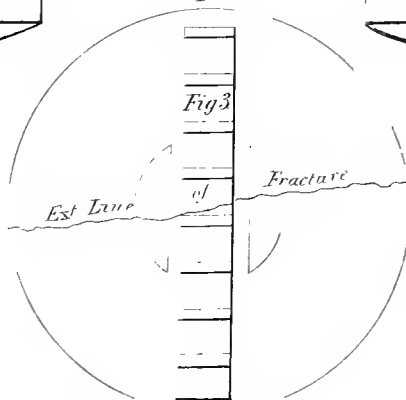
Of the Powder.

The powder used in these experiments was made by the Messrs. Dupont; was rather fine grained, for cannon powder; the proof range by the eprouvette varied between 295 and 318 yards; it was new, and is believed to have been a very quick, and therefore a very severe powder upon the gun.

The velocity of the 10-inch solid shot of 125 pounds, and sabot 1.5 pounds, with 18 pounds of this powder, was 1308 feet per second by the gun pendulum, and that of the 10-inch shell of 101.75 pounds, and sabot of 1.5 pounds, with 18 pounds of the same powder, was 1427 feet per second by the same pendulum.

This powder is unquestionably too quick for guns of large calibre; nor is it believed that the increase in velocity and range at all compensates for the heavy strain to which the gun is subjected, by the use of the excessive charges now assigned to heavy guns.

TABLE *showing the enlargement of the bores above their original diameters, after the under-mentioned number of fires, in thousandth of an inch.*

Distance from Muzzle.	2d Fire.	(Proof.)	17th Fire.		47th Fire.	70th Fire.	103d Fire.	153d Fire.	213th Fire.	270th Fire
	331 Hollow.	332 Solid.	331 Hollow.	332 Solid.	331 Hollow.	331 Hollow.	331 Hollow.	331 Hollow.	331 Hollow.	331 Hollow.
10 in.	.002	.001	.002	.001	.002	.003	.003	.003	.003	.003
20	2	1	2	1	2	2	2	2	2	2
30	1	1	1	1	1	1	1	1	2	3
40	1	1	1	1	1	1	1	1	3	3
50	1	1	1	1	1	1	1	1	2	3
60	2	0	2	1	2	2	2	2	4	7
70	1	0	1	0	1	1	1	2	3	4
80	2	1	2	0	2	2	2	2	2	4
81	1	1	1	1	1	1	1	1	2	4
82	2	3	2	3	2	2	2	2	3	6
83	1	2	1	2	1	1	1	1	3	5
84	1	2	1	2	1	1	1	1	3	5
85	2	2	3	2	3	4	4	4	5	6
86	3	4	3	4	3	4	4	4	5	7
87	4	4	4	4	4	4	4	5	7	7
88	4	7	4	4	4	5	5	5	7	9
89	3	7	5	15	5	5	6	6	9	12
90	6	12	13	39	13	13	13	13	18	19
91	8	19	15	72	16	16	17	21	36	35
92	10	20	19	52	26	26	29	33	48	60
92½	12	17	23	52	26	28	39	44	61	66
						35	55	58	75	80
Diameter in plane of axis, and interior of vent.										

TABLE *showing the enlargement of the chamber of Gun No.* 331 *(cast hollow), after the under-mentioned numbers of fires, in thousandths of an inch.*

Distance from Muzzle.	2d.	17th.	47th.	70th.	103d.	153d.	213th.	270th.	H.
99½	3	5	7	8	8	8	14	18	10
103	2	5	6	6	6	6	7	11	8
106½	4	7	7	7	7	7	7	9	8

TABLE *showing the enlargement of the chamber of Gun No.* 332 *(cast solid), after the under-mentioned numbers of fires, in thousandths of an inch.*

Distance.	2d.	17th.							
99½	9	14							
103	5	9							
106½	4	9							

In both guns the greatest enlargement was in a plane containing the axis of the bore, and the interior of the vent ; it has always, heretofore, been in the vertical plane through the vent. These facts seem to show that the position of the interior of the vent exercises an influence over the plane of greatest enlargement ; and, if so, might not the enlargement caused by the indendation of the shot be prevented by igniting the charge in the axis of the bore at the bottom of the chamber ?

Elongation per inch of metal in bore of   hollow gun after 270th fire = .0066 in.
  "   "   "   "   solid   "   "   17th fire = .0072 in.
  "   "   "   chamber of hollow "   "   270th fire = .00225 in.
  "   "   "   chamber of solid   "   "   17th fire = .00175 in.

TABLE *showing the enlargement of the vent of Gun No. 331 (cast hollow), after the undermentioned numbers of fires, in hundredths of an inch.*

Distance from Exterior.	2d.	17th.	47th.	70th.	103d.	153d.	213th.	270th.
2	0	0	0	0	2	4	5	10
3	0	0	0	0	2	4	6	11
4	0	0	0	0	2	4	8	12
5	0	0	0	2	2	5	10	15
6	0	0	0	2	3	5	7	15
7	0	0	0	2	3	6	12	15
8	0	0	2	2	4	7	12	18
9	0	0	2	2	4	10	16	28
10	0	0	2	2	4	7	14	20
11	0	0	2	2	4	10	21	30
12	0	0	2	3	5	8	20	22
13	0	0	0	0	0	0	0	8

Though the instrument showed no enlargement of the interior of the vent till after the 270th fire, yet it was evident, from inspection after the gun was broken, that enlargements had been effected at this point at a much earlier period; but it was principally in a longitudinal plane, the appearance after fracture being thus : —

The vent of gun No. 332 (cast solid) was not perceptibly enlarged, as shown by inspection after the gun was broken.

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TABLE *showing the tensile strength and density of specimens from various parts of the two guns, there being two specimens for each number, one from each gun, and from corresponding positions.*

Marks and Numbers of Specimens.	Densities.		Tenacities.	
	G. 331 Hollow.	G. 332 Solid.	G. 331 Hollow.	G. 332 Solid.
1, . . .	7.205	7.154	30062	29179
2, . . .	7.205	7.159	31831	28389
3, . . .	7.191	7.150	28740	30770
4, . . .	7.194	7.143	29311	24846
5, . . .	7.205	7.147	34510	28383
6, . . .	7.225	7.127	27850	28306
7, . . .	7.235	7.178	30070	31369
8, . . .	7.233	7.179	30941	31227
9, . . .	7.212	7.145	32720	28614
10, . .	7.225	7.189	32292	30947
11, . . .	7.223	7.134	31050	27192
12, . . .	7.216	7.192	32647	30747
13, . . .	7.218	7.193	30733	30770
H. 1, . . .	7.221	7.155	33712	31831
H. 2, . . .	7.217	7.166	33620	31389
H. 3, . . .	7.217	7.166	33590	32811
M. 1, . . .	7.217	7.156	29720	29187
M. 2, . . .	7.200	7.151	30290	29797
M. 3, . . .	7.220	7.154	31671	29869
Mean, . .	$7.214\frac{13}{18}$	$7.159\frac{17}{18}$	$31.334\frac{14}{18}$	$29.769\frac{13}{18}$

Figures 1, 2, 3 and 4, Plate No. 4, show the parts of the guns from which the specimens were taken, the numbers on the plate corresponding with those in the table. Specimens 6, 7, and 8 of gun No. 331, are of greater density and less tenacity than the general average; the cause of this is believed to be that the metal in this part of the gun was subjected to greater pressure of gas, and to the balloting of the shot; the density being thus increased, while the tenacity was diminished.

PLATE IV.

Fig 1.

2 3 1

2 3 1

Gunhead

3

Fig. 2

2 1

Muzzle of Gun.

3

Fig 3

2 1

13 6 11

1

12 6 11

8 7 7

7.5 1 2 3 4 5 6

Cushing
Specimen

Section on A.B.

A 9 5 B

6 7.5

10.75

14

Fig. 4

9 4 1 2 5

3
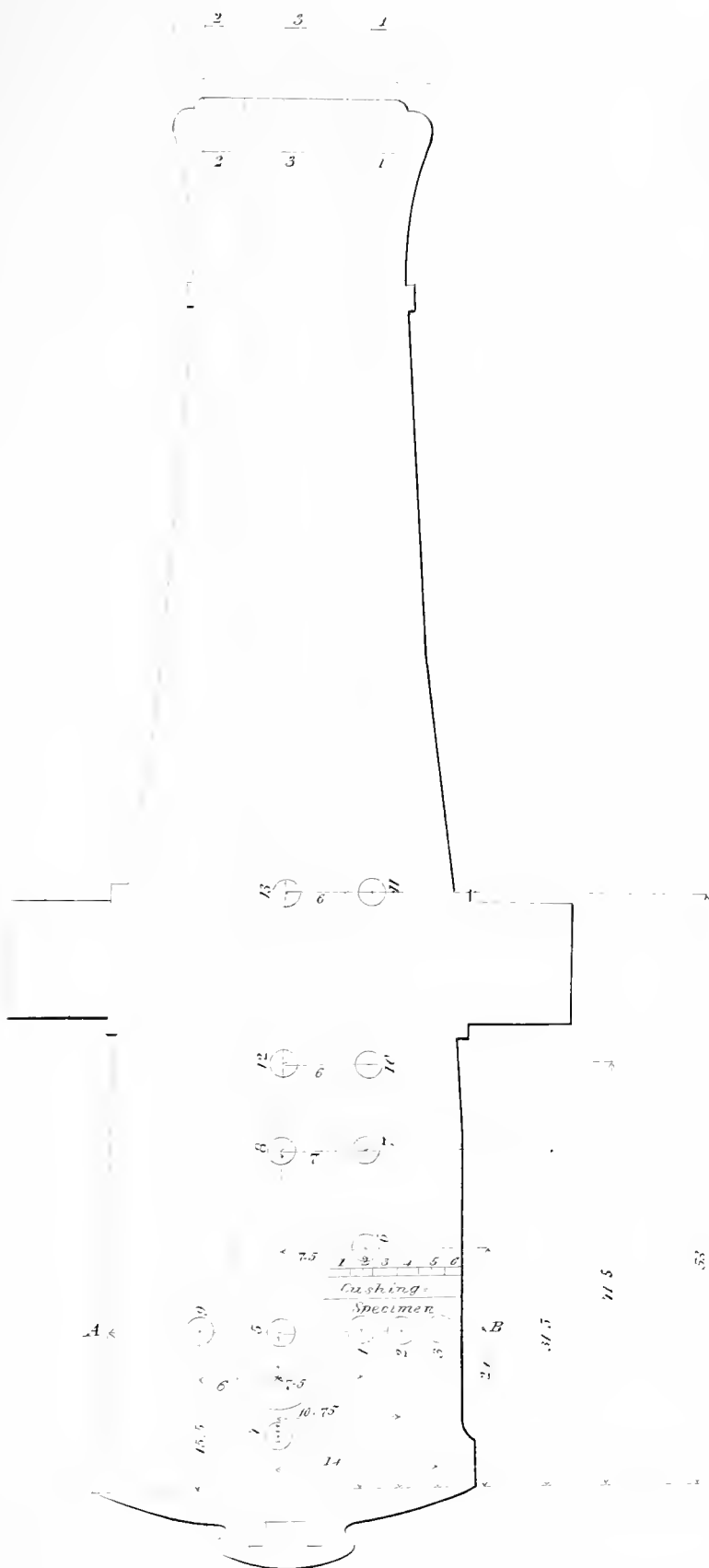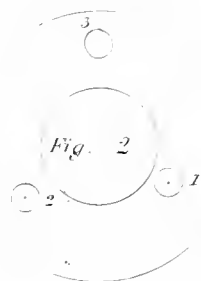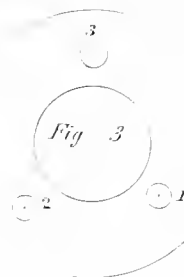
Comparison of Head with Muzzle Specimens, from both guns.

NO. OF SPECIMENS.	GUN No. 331 (cast hollow).			
	Densities.		Tenacities.	
	Head.	Muzzle.	Head.	Muzzle.
1	7.221	7.217	33712	29720
2	7.217	7.200	33620	30290
3	7.217	7.220	33590	31671
	7.218	7.212	33641	30560
Mean Difference, . .	.006		3081	

	GUN No. 332 (cast solid).			
	7.155	7.151	31831	29187
	7.166	7.151	31389	29797
	7.166	7.154	32811	29869
	7.162	7.152	32010	29618
Mean Difference, . .	.010		2392	

The above results show a difference in both density and tenacity between the specimens taken from the gun heads, and those taken from the muzzles of the guns; these specimens were only separated in the casting by the width of the necking tool, say .75 of an inch. The discrepancies cannot, therefore, be ascribed to difference of position in the casting, but are believed to be due to deterioration of the qualities of the metal, caused by the violent series of vibrations to which the gun is subjected at each discharge in firing. And this view seems to be sustained by the fact that the difference in tenacity is greater in the gun which has been oftenest fired.

Comparison of tensile strength of radial with tangential specimens from the same gun.

Gun No. 331 (cast hollow).			Gun No. 332 (cast solid).		
Number of Specimens.	Radial.	Tangential.	Number of Specimens.	Radial.	Tangential.
5 and 1,	34510	30062	5 and 1,	28383	29179
8 and 7,	30941	30070	8 and 7,	31227	31369
12 and 10,	32647	32292	12 and 10,	30747	30947
13 and 11,	30733	31050	13 and 11,	30770	27192
	32208	30868		30282	29671
Mean Difference,	1340		Mean Difference,	611	

These results show the radial specimens to be something stronger than the tangential, from the same cross section of the gun, and are in confirmation of the theory of Mr. Robert Mallet, viz., that the major crystalline axes correspond in direction with that of the passage of heat in cooling; or, that they are perpendicular to the cooling surface, and that the metal is strongest in that direction.

These results further sustain this theory, in the fact that the difference between the strength of the radial and tangential specimens is greatest in those from the hollow cast gun, which was most rapidly cooled.

TABLE *showing the compression per inch, in length, caused by the undermentioned weights per square inch (radial specimens).*

Gun No. 331 (cast hollow).			Gun No. 332 (cast solid).		
Number of Specimens.	Weight per square inch.	Compression per inch.	Number of Specimens.	Weight per square inch.	Compression per inch.
1	72571	.03537	1	73428	.07017
2	71730	.03560	2	73140	.06825
3	72290	.03375	3	72855	.06406
4	72855	.03281	4	73140	.07480
5	73140	.02299	5	72855	.09422
6	73140	.02617	6	73140	.10080

The specimens from which the results recorded in the above table were obtained, were taken from radial specimens opposite the middle of the chamber.

No. 1 being cut from the end next the chamber, and the others numbered from the inner to the outer end of the specimen, each number having two specimens, one from each gun.

These results show from two to four times as much compression in the specimens from the solid gun, as in those from the hollow one; and this property of resistance to a crushing force will be shown further forward in this Report, to exercise an important influence on the endurance of guns.

TABLE *showing the change of form produced by a crushing force of* 15.000 *pounds on the undermentioned specimens, and their ultimate resistance to a crushing force.* (*Same specimens as described in the preceding Table.*)

GUN No. 331 (CAST HOLLOW).

Number of Specimens.	Diameters.		Lengths.		Ultimate Crushing Force.
	Before.	After.	Before.	After.	
1	.513	.525	1.244	1.200	25400
2	.516	.525	1.264	1.219	23700
3	.514	.523	1.274	1.231	22900
4	.512	.522	1.280	1.238	22200
5	.511	.518	1.261	1.232	24400
6	.511	.519	1.261	1.228	20900

GUN No. 332 (CAST SOLID).

Number of Specimens.	Diameters.		Lengths.		Ultimate Crushing Force.
	Before.	After.	Before.	After.	
1	.510	.533	1.254	1.166	20700
2	.511	.533	1.260	1.174	19800
3	.512	.534	1.280	1.198	19600
4	.511	.535	1.270	1.175	19900
5	.512	.546	1.263	1.144	19800
6	.511	.544	1.259	1.132	18600

It is believed that specimens Nos. 1 and 2, from gun No. 332, should have been Nos. 6 and 5, and *vice versa*, as it is thought that the workman misunderstood the directions given for marking, after turning.

The results indicate that No. 6 should be from the interior instead of the exterior of the gun, and a comparison of the ultimate resistance of No. 6 gun 331, with that of No. 1 gun 332, adds strength to this belief, as there should be less difference in quality between the outer portions of the two guns, than in any other corresponding parts; the circumstances of cooling being more nearly identical in these than in any other portions of the guns.

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TABLE *showing the compression, restoration and set, of radial specimens, one from each gun, and from corresponding parts (inner ends of radii).*

	GUN No. 331 (CAST HOLLOW).			GUN No. 332 (CAST SOLID).		
	ORIGINAL DIAMETER = .688 in. ORIGINAL LENGTH = 5.52 in.			ORIGINAL DIAMETER = .685 in. ORIGINAL LENGTH = 5.52 in.		
Weights.	Compression.	Restoration.	Set.	Compression.	Restoration.	Set.
1000 lbs.	.0005	.0005	.0000	.0020	.0020	.0000
2000	.0011	.0011	.0000	.0025	.0025	.0000
3000	.0020	.0020	.0000	.0030	.0030	.0000
4000	.0025	.0024	.0001	.0035	.0035	.0000
5000	.0033	.0031	.0002	.0040	.0039	.0001
6000	.0047	.0044	.0003	.0044	.0042	.0002
7000	.0058	.0054	.0004	.0060	.0057	.0003
8000	.0065	.0058	.0007	.0080	.0075	.0005
9000	.0076	.0066	.0010	.0085	.0077	.0008
10000	.0090	.0078	.0012	.0095	.0082	.0013
11000	.0105	.0091	.0014	.0110	.0090	.0020
12000	.0115	.0097	.0018	.0130	.0100	.0030
13000	.0133	.0103	.0030	.0143	.0098	.0045
14000	.0143	.0105	.0038	.0190	.0080	.0110
15000	.0168	.0118	.0050	.0230	.0101	.0129
16000	.0217	.0127	.0090	Began to bend.		
17000	.0267	.0137	.0130			
18000	.0333	.0133	.0200			
19000	.0523	.0183	.0340			
20000	.0623	.0163	.0460			
	Began to bend.					

| Diameter after 20000 lbs. = .691. | Diameter after 15000 lbs. = .686. |

TABLE *showing the compression, restoration and set, of radial specimens, one from each gun, and from corresponding parts (outer ends of radii).*

GUN No. 331 (CAST HOLLOW).				GUN No. 332 (CAST SOLID).		
ORIGINAL DIAMETER = .692 in. ORIGINAL LENGTH = 5.52 in.				ORIGINAL DIAMETER = .682 in. ORIGINAL LENGTH = 5.5 in.		
Weights.	Compression.	Restoration.	Set.	Compression.	Restoration.	Set.
1000 lbs.	.0007	.0007	.0000	.0018	.0018	.0000
2000	.0016	.0016	.0000	.0028	.0027	.0001
3000	.0024	.0024	.0000	.0039	.0032	.0007
4000	.0033	.0033	.0000	.0049	.0041	.0008
5000	.0040	.0040	.0000	.0060	.0051	.0009
6000	.0048	.0048	.0000	.0070	.0061	.0009
7000	.0054	.0053	.0001	.0084	.0073	.0011
8000	.0064	.0060	.0004	.0097	.0082	.0015
9000	.0074	.0066	.0008	.0122	.0101	.0021
10000	.0085	.0074	.0011	Not	reliable.*	
11000	.0097	.0084	.0013	.0212	.0104	.0108
12000	.0108	.0086	.0022	.0220	.0110	.0110
13000	.0130	.0090	.0030	.0236	.0113	.0123
14000	.0153	.0113	.0040	.0300	.0110	.0190
15000	.0188	.0129	.0059	.0460	.0135	.0315
16000	.0224	.0143	.0081	Specimen began to bend at 13000 lbs.; only reliable above 10000 lbs.		
17000	.0277	.0127	.0150			
18000	.0388	.0128	.0260			
19000	.0551	.0150	.0401			
20000	.0652	.0157	.0495			
	Began to bend at 20000 lbs.					

Length after 20000 lbs. = 5.470 in. Diameter after 20000 lbs. = .693 in.	Length after 15000 lbs. = 5.486 in. Diameter after 15000 lbs. = .683 in.

* Specimen shifted while measuring set.

These specimens were turned with collars or projections left near each end, and the lengths given in the table are the distances between the collars. The space between the collars was surrounded by a cast iron sheath about .75 inch less in length than this space, and the compression was measured by inserting a graduated wedge between the upper end of the sheath and the lower side of the upper collar, before any pressure was applied, and again after the application of the force whose effects were to be measured; the difference of these readings gave the amount of compression which that portion of the specimen between the collars had undergone, there being no pressure upon the sheath at any time.

The taper of the wedge was .01 inch to 1 inch.

TABLE *showing the compression and set of a cylinder 5.5 in. long and .508 in. diameter, cut longitudinally from trial cylinder (A. 1. C.)*

Weight.	Compression.	Set.	Weight per square inch.	Compression per inch.	Set per inch.
100 lbs.	.0000 in.	.0000 in.	493 lbs.	.00000 in.	.00000 in.
200	.0005	.0000	986	.00009	.00000
500	.0010	.0000	2465	.00018	.00000
1000	.0015	.0000	4930	.00027	.00000
1500	.0020	.0000	7395	.00036	.00000
2000	.0025	.0000	9860	.00045	.00000
3000	.0040	.0005	14790	.00072	.00009
4000	.0055	.0007	19720	.00100	.00013
5000	.0065	.0010	24650	.00118	.00018
6000	.0085	.0012	29570	.00155	.00022
7000	.0098	.0018	34510	.00178	.00033
8000	.0124	.0030	39440	.00225	.00054
9000	.0160	.0055	44370	.00291	.00100
10000	.0197	.0098	49300	.00358	.00174
11000	.0384	.0250	54230	.00698	.00454
12000	.0550	.0493	59160	.01000	.00896

Diameter after 10.000 pounds = .512.

Diameter after rupture (12.000 lbs.,) = .513.   Broke by bending.

Specimens began to bend at 8000 pounds; therefore results from weights above 8000 pounds, are not strictly reliable.

A fragment of this specimen   1.25 in. long and .510 in. diameter,
After having borne 14000 lbs., was 1.235 "   "   " .515 "   "
"   "   "   20000 "   " 1.180 "   "   " .526 "   "
"   "   "   25000 "   " 1.074 "   "   " .558 "   "

TABLE *showing the elongation per inch, at the beginning of permanent set, and at the moment of rupture, in parts of an inch.*

MARKS.	Elongation at beginning of set.	Elongation at rupture.	REMARKS.
A. 1. C. 1	.002186	.007922	Longitudinal specimen from trial cylinder.
G. 331. 1	.002328	.010057 ⎫	Radial specimens contiguous to those for com-
G. 331. 2	.002488	.013300 ⎭	pression.
G. 332. 1	.002060	.010580 ⎫	Radial specimens contiguous to those for com-
G. 332. 2	.001983	·009710 ⎭	pression.

The elongation at permanent set, and that due to different forces, up to that of rupture, being qualities next in importance to the actual strength of the metal, it is much to be regretted that the testing machine at this place is not adapted to the accurate determination of these qualities; and the

construction of a machine adapted to this kind of test, in addition to those to which the present machine is adapted, is earnestly recommended.

The values for elongation at set and rupture, recorded in the above table, were obtained by bending a regularly tapered sample around segments of circles, whose radii were known.

For the elongation at the beginning of permanent set, the specimen is bent, beginning at the thin end around the arc. It is then removed, and the convex side of the thin end placed in contact with a straight edge, and the thickness of the specimen at the point where it begins to leave the straight edge is measured, and a piece of the same metal, of this or any less thickness, could be bent entirely round a circle of the radius of the arc, round which the specimen was bent, without receiving a permanent set. Then if we suppose the neutral axis of the specimen to be intermediate between the two surfaces, half the thickness of the specimen divided by the radius of the arc, plus the entire thickness of the specimen, will give the elongation at permanent set.

The same principle applies in determining the elongation at the moment of rupture. The specimen being bent around an arc of known radius, until it breaks, then, on the same supposition as to the neutral axis, half the thickness of the specimen at the point of rupture, divided by the radius of the arc, plus the entire thickness, will give the elongation at the moment of rupture.

Owing to uncertainty as to the position of the neutral axis, and to the fact that the very thin lamina on the exterior of the specimen whose elongation is measured, is connected with others less highly strained, this method is not deemed as reliable for the *actual* elongation as that in which the entire section of the specimen is subjected to the same tensile strain; it, however, answers very well as a means of comparing one metal with another.

Thus an inspection of the foregoing table shows the stiff, strong specimen from (A. 1 C.) to have extended more before taking a permanent set, than the weaker and softer specimen from gun No. 332, while the latter undergoes a greater extension before *rupture ;* the medium iron in gun No. 331, being superior to both, in both qualities.

And a comparison of the results obtained from the two guns in all the tests to which the metal has been subjected, goes to show the superiority of that in gun No. 331, cast hollow, over that in gun No. 332, cast solid.

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And this is what should have been expected, since the metal was sufficiently low to require, in order to develop its best qualities, a more rapid rate of cooling than was applied to the solid gun No. 332, or than can be, with safety, applied to any solid cast gun of this calibre.

Summary of all the tests to which the metal of these guns was subjected.

KIND OF TEST.	Gun No. 331 (cast hollow).	Gun No. 332 (cast solid).
Specific gravity, ...	7.215	7.160
Weight of guns, ...	15218 lbs.	15139 lbs.
Tensile strength, ...	31335 lbs. per sq. in.	29770 lbs. per sq. in.
Compression per inch by 73093 lbs. per square inch,	.03131 in.	.07871 in.
Ultimate resistance per square inch to a crushing force, ...	112480 lbs.	96219 lbs.
Elongation per inch at beginning of permanent set,	.002408 in.	.002021 in.
Elongation per inch at moment of rupture, . .	.011678 in.	.010145 in.
Number of times fired, ...	315 burst.	26 burst.

The values for specific gravity and tensile strength, are the mean results of 19 specimens each.

The values for compression per inch, and for ultimate resistance to a crushing force, are each means of six specimens. Those for elongation at beginning of permanent set, and at rupture, are means of two specimens each.

TABLE *showing the mechanical tests and endurance of five pairs of guns, one of each pair cast solid, and the other hollow, both guns of each pair being cast at the same time, and from the same metal.*

No. of Gun.	Calibre.	Density.	Tenacity.	Weight of charge.	Weight of shot.	How cooled.	No. of fires.	REMARKS.
{ 1	8 inch.	7.221	27014	10 lbs.	64 lbs.	Exterior.	84 }	Burst at 85th fire.
{ 2	8 "	7.226	27962	10 "	64 "	Interior.	250 }	Burst at 251st fire.
{ 3	8 "	7.286	37984	10 "	64 "	Exterior.	72 }	Burst at 73d fire.
{ 4	8 "	7.286	37816	10 "	64 "	Interior.	1500 }	Has been fired 1500 times ; not burst.
{ 5	10 "	7.290	37122	18 "	125 "	Exterior.	19 }	Burst at the 20th fire.
{ 6	10 "	7.294	38513	18 "	125 "	Interior.	248 }	Burst at the 249th fire.
{ 160	32 lbs.	7.281	34307	8 " / 10¾ "	32 " / 32 "	Interior.	1000 / 20 }	Burst at the 1021st fire, with 16 lbs. of powder, and 2 shot = 64 lbs.
{ 161	32 "	7.271	33590	8 " / 10¾ "	32 " / 32 "	Exterior.	1000 / 5 }	Burst at the 1006th fire.
{ 331	10 inch.	7.215	31385	18 "	125 "	Interior.	314 }	Burst at the 315th fire.
{ 332	10 "	7.160	29770	18 "	125 "	Exterior.	25 }	Burst at the 26th fire.

Total number of fires from five solid guns = 1208.

Total number of fires from five hollow guns = 3336.

Total number of fires from four solid Columbiads = 202.

Total number of fires from four hollow Columbiads = 2315.

One hollow cast 8-inch Columbiad, unbroken, after 1500 rounds.

Solid cast guns *all* broken.

These results appear to leave no doubt as to the superiority of the hollow over the solid cast guns, *while new ;* what effect time may have upon them can only be ascertained by experiments; but it is difficult to understand how time could ever so far change their relative endurance, as to cause the solid cast guns to surpass those cast hollow in this quality.

The tests show the metal in the solid cast gun to be inferior, in every quality, to that cast hollow; and it is believed that this inferiority will become more marked as the iron from which the guns are made becomes softer; and it is now conceded by all who are acquainted with the subject, that solid cast guns cannot, with safety, be made of high iron. They *must*, therefore, be made of soft, and consequently weak iron, whose qualities would be improved by a more rapid rate of cooling than can be safely applied to the solid cast gun.

The only effect of time is supposed to be to relieve the metal from the strain to which it had been subjected in cooling, it not being supposed to effect any change in its actual character.

It would, therefore, appear to be reasonable and safe to predict that the *utmost* effect which time could produce, would be to bring their endurance to an equality; and should this be found to be the case, which is not probable, it would still leave the hollow cast gun superior to the other, as it is believed that it may be mounted for service as soon as finished, and relied on for at least 150 rounds, for 10-inch guns; while the solid cast gun cannot be relied on for a single fire when *new ;* nor can any limits, below which it shall be safe, be with any degree of certainty assigned to it after any lapse of time.

The cause of this difference is believed to be that the hollow cast gun is so far relieved from strain in cooling, as to remove the possibility of its ever being injured in that process; and the more perfect this relief, the more nearly will the endurance of the new gun approach that of the same gun, after any lapse of time.

While in the new solid cast gun, it is certain that the interior is under a very heavy strain, which requires time for its removal; and there is no certainty that this strain has not been sufficiently great to produce either actual cracks, or such a degree of molecular separation in the interior portions of the gun, as no lapse of time will remedy.

That *good* solid cast guns *may* be made, is not doubted, for they *have* been made; but that it is possible to distinguish, before the trial, the safe from the unsafe gun, is not believed.

And the number of comparatively recent failures in the proof of guns offered for inspection by our most experienced gun founders, and of those by them rejected for cracks and other imperfections, discovered in boring, added to those which have stood the proof and been received, but burst by a few additional rounds, would seem to show that this incredulity is not without good foundation.

To remove this *uncertainty* is the first great desideratum in the manufacture of cannon; the next is to place the limit of safety as high as possible. Therefore the introduction of any mode of casting which will enable us to fix a limit, though it should be a low one, below which guns are actually safe, must be regarded as an important step forward in the art of gun founding.

From the experiments already made, the mode of hollow casting, and internal cooling, gives fair promise of enabling us to fix a limit of safety which will be above the number of fires to which any *one* gun would likely be subjected, during any siege, or even during any war.

Experiments alone will give us the facts, and settle the question; and they should be made with as little delay as possible, and on such a scale as to go to the bottom of the subject; and no additional heavy guns should be cast for service until further experiment shall point out the best mode of manufacture, and the best model of gun.

Initial Velocities of 10-*inch Shot and Shells.*

The 10-inch gun being suspended, for convenience in firing, while testing its endurance, was converted into a gun pendulum, by accurately weighing all the material which moved in connection with the gun at each discharge, and attaching a graduated arc, with a movable slide, for measuring the arc of recoil.

The formula by which the velocities were computed was that for the gun pendulum used by Major A. Mordecai, in his experiments on gunpowder, viz. :

$$v = 2 \; sine \; \tfrac{1}{2} \; A \, p \, 8 \; \frac{\sqrt{\overline{G \, o} - c \; N}}{i}, \text{ in which}$$

$$b\frac{D^2}{d^2} + \frac{c}{2}.$$

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v = initial velocity in feet per second.

A = arc of recoil of the pendulum.

p = weight of pendulum = 15823 pounds.

g = distance of centre of gravity of pendulum from axis of motion = 289.33 inches.

G = force of gravity = 32.155 feet.

o = distance between axis of suspension and oscillation = 294.83 inches.

i = distance between axis of suspension and of the gun = 292.1 inches.

b = weight of shot and sabot = 123.5 + 1.5 = 125 pounds.

c = weight of charge = 18 pounds.

N = 1600 feet.

D = diameter of bore = 10 inches.

d = diameter of shot = 9.87 inches.

The gun made 437 oscillations in 20 minutes.

The arcs of recoil, with the same weights of powder and the same shot, were as follows, viz. :—

1st fire,	.	.	.	.	. 27° 08′
2d do	.	.	.	.	. 26° 56′
3d do	.	.	.	.	. 27° 37′
4th do	.	.	.	.	. 27° 12′
5th do	.	.	.	.	. 27° 26′ Mean = 27° 22′.
6th do	.	.	.	.	. 27° 21′
7th do	.	.	.	.	. 27° 44′
8th do	.	.	.	.	. 27° 34′

These data give the velocity of the solid shot = 1308 feet per second.

The arcs of recoil, with 18 pounds of powder and the same shell = 101.75 pounds, and sabot 1.5 pounds, and same pendulum, were as follows, viz. :—

1st fire,	.	.	.	.	. 25° 17′
2d do	.	.	.	.	. 25° 05′
3d do	.	.	.	.	. 25° 27′ Mean = 25° 21′.
4th do	.	.	.	.	. 24° 48′
5th do	.	.	.	.	. 26° 07′

Diameter of shell = 9.87 inches, and N = 1600 feet.

These data give the velocity of the shell = 1427 feet per second.

OF THE VELOCIMETER.

Its Object.

This instrument is intended to measure the successive increments of velocity impressed, by the expansive force of the ignited charge, upon the shot, from the time it leaves its seat in the gun, till it reaches the muzzle.

Principles on which its Action depends.

It depends, for its action, upon the fundamental principles of mechanics, that no connected system of bodies has the power of changing the position of its centre of gravity; and that the same force will impress, upon different bodies, equal quantities of motion in equal times, irrespective of their masses.

Description.

It consists simply of a cylinder, mounted in a frame, with the means of communicating to it a uniform motion of rotation about its axis; and of a movable slide, which carries a marking point, and is so placed as to move parallel with the axis of the cylinder.

Its position when in Use.

When in position for use, the instrument is firmly fixed with the axis of the cylinder parallel to that of the gun, and at such a distance in its rear as to be entirely below the arc described in its recoil; the movable slide being on a level with the stop by which it is moved, as the gun recoils. This stop is bolted to the under side of the bar which connects the breech and muzzle slings of the gun, is the lowest point of the system, and likewise moves the registering slide on the arc which measures the recoil of the pendulum.

The space between this stop and the end of the sliding bar is supplied by a wooden rod, shod at both ends, with iron or brass. The forward end of this rod should be permitted to disengage itself from the stop as soon as the shot has left the gun, otherwise something would be broken.

The rear end of the sliding bar should also have a wooden cushion to strike against, otherwise the marking point would be broken off at each discharge.

Explanation of Action.

Let us suppose the pendulum to be at rest, its centre of gravity will be in the vertical plane of the axis of suspension.

Now suppose the cartridge so far inserted into the gun that its centre of gravity shall coincide with that of volume of the bore, and the shot so far inserted that its centre of gravity shall be in the plane of the face of the muzzle, these weights will cause the pendulum to move to the rear; the centre of gravity of the *new* system, when at rest, being in the vertical plane of the axis of suspension. If now the sliding bar be, by the interposition of the aforesaid rod, placed in contact with the stop, and the cylinder revolved, the marking point will trace a continuous line around the cylinder.

Now suppose the cartridge and shot both rammed home; they will now occupy a position in rear of the vertical plane of the axis of suspension, and will cause the pendulum to move forward until the centre of gravity of the system again rests in the vertical plane of the axis of suspension. If now the rod and slide be moved forward, in contact, till the end of the rod again comes in contact with the stop, and the cylinder be again revolved, the marking point will trace another continuous line around the cylinder.

The distance between the two lines thus traced on the cylinder is equal to that through which the stop moves, while the shot is passing from its seat to the muzzle of the gun.

Let the cylinder be now put in motion, and after having attained a uniform velocity, suppose the charge ignited; the shot and charge will move forward, and the pendulum backward, while the centre of gravity of the system will remain at rest, so long as the shot remains in the gun, and at the moment when the shot leaves its seat, the marking point will leave the forward line around the cylinder, and will cross the rear line at the moment when the shot is leaving the muzzle, all the parts of the system occupying, at this moment, the same positions as those first described with the shot in the muzzle.

The cylinder being in motion while the marking point is moving to the rear, will cause it to describe a helix on the surface of the cylinder, whose inclination to the elements of the cylinder will become less as the velocity of the marking point becomes greater; and that portion of this helix which is traced after the velocity of recoil has become sensibly uniform, and before gravity has sensibly diminished the velocity of recoil, will develop into a right line; and this portion ought to begin just in the rear of the rear line on the cylinder, since the gas remaining in the gun, at the moment when the shot leaves, ought, in escaping, to impress some additional velocity upon the pendulum; otherwise it ought to commence on that line.

And, in practice, the curvature is not perceptible in rear of that line.

This instrument is intended to be used in connection with either the gun or ballistic pendulum.

Therefore the velocity of the shot, at the moment it leaves the gun, is known.

This gives the value, in velocity, of the angle formed by the element of the cylinder, and the tangent to the curve at the point where it crosses the rear line traced by the marking point upon the cylinder; and that portion of the curve between the lines traced upon the cylinder connects this value with that of every other angle which can be formed by the elements of the cylinder and tangents to this curve.

The cylinders used in these experiments were of birch wood, the marking point being of steel, burnished so as to make a fine mark on the surface of the cylinder. The curves described on the cylinders were retraced by a fine-pointed lead pencil, and the curves thus colored were taken on tissue paper, and transferred to that on which they now are.

This mode of determining the velocity of the shot, at different points, along the bore of the gun, is not supposed to give that degree of accuracy to its results which would be obtained by successively diminishing the length of the bore, so as to make its entire length equal to the distance from the bottom of the bore to the point at which the velocity is required, and using the gun thus shortened in connection with the use of the ballistic pendulum.

This method is intended rather to give an ocular demonstration, or a view, of the relative velocities of the shot at different points along the bore of the gun.

To explain more fully how the velocity of the shot at the muzzle of the gun is connected by the curve with that at any other point, let (a b) and (c d) Fig. 2, Plate 5, be the developed lines traced around the cylinder, and let (e p g) be the curve developed; traced by the marking point when moving to the rear, as before described, the point (e) corresponds to the moment of time when the shot left its seat, and (p) to that when it left the muzzle; and (l p) represents the time occupied by the shot in traversing the entire bore of the gun.

Let the tangent to the curve at the point (p) be extended till it meets the line (a b), and from the point of intersection let the line (n g) be drawn parallel to the developed elements of the cylinder, the line (p g) will represent

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the time required by the shot to traverse the length of the bore when moving with the velocity with which it left the muzzle.

Let it now be required to find the distance from the bottom of the bore at which the velocity of the shot was one-half of that with which it left the muzzle. Now since the space passed over = velocity multiplied by the time, if the velocity be one-half, the time will be doubled for the same distance; if, therefore, $(p\ m) = (p\ g)$ be laid off on the line $(c\ d)$, and the points (m and n) joined by a right line, and this line be moved parallel to itself till it becomes tangent to the curve, the point of contact will correspond to that in the gun at which the velocity of the shot was one-half of that at the muzzle; and if $a =$ length of bore, and $x =$ distance required, then $n\ t : n\ g :: x : a$. In like manner the value of x for any assumed velocity may be found.

The dotted curve (parabola) $(e'\ P')$, Fig. 1, is that which *would* be described if the shot were moved by a force of uniform intensity, and such that it would leave the gun with a velocity equal to that produced by the irregular force; and indicates that the pressure exerted by the expansive force of ignited, grained powder, is very much greater in the rear than in the middle and forward parts of the bore.

And these curves afford the data for approximating with considerable accuracy to the statical pressure per inch exerted on the bore of the gun at different points.

The centre of gravity of the pendulum (whose weight = 15.823 pounds), is found to have been elevated by the force of the powder, through a vertical height of 2.7 feet; and the distance through which it moved while acquiring the velocity due to this height is found to be (.06) six hundredths of a foot; then supposing the pressure per inch to have been of uniform intensity, while the pendulum was moving through this distance, we have for its value (p).

$$p = \frac{15823 \times 2.7}{.06 \times 78.54,} = 9066 \text{ pounds.}$$ (the area of a section of the bore) $= 78.54$.

The curves described show that the gun and shot had acquired one-half their final velocity in about one-fourth of the time required for the shot to pass from its seat to the muzzle of the gun; therefore the mean pressure, in the bore of the gun, during the first fourth of that time, must have been double that for the whole time, or $= 18132$ lbs. per square inch; they further show that the shot and pendulum had acquired *one-fourth* of their final velocity in about one-sixteenth part of the whole time aforesaid, and that the

PLATE V.

Fig. 1

p

e

Fig. 2

q

c   *l*   *q q*   *p*   *m*   *d*

a   *c*   *n n*   *b*

PLATE VI.

Fig. 1.

Fig. 2

PLATE VII.

Fig. 1.

Fig. 2.

PLATE VIII.
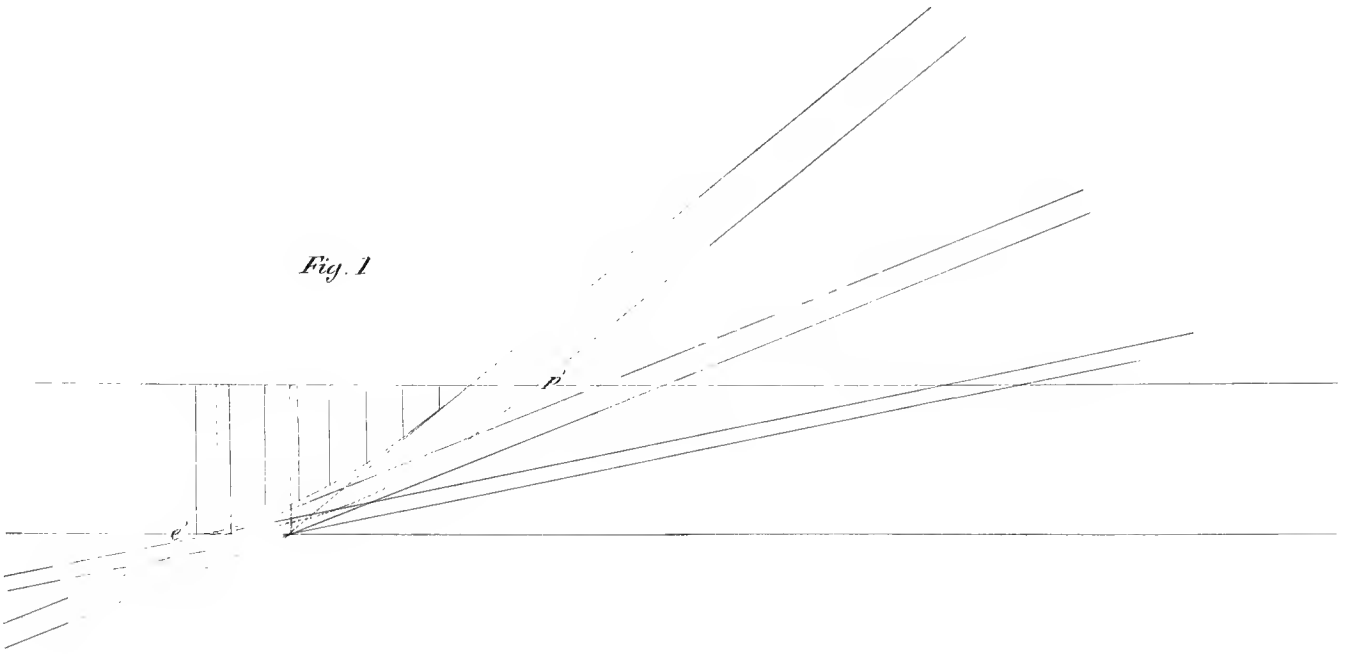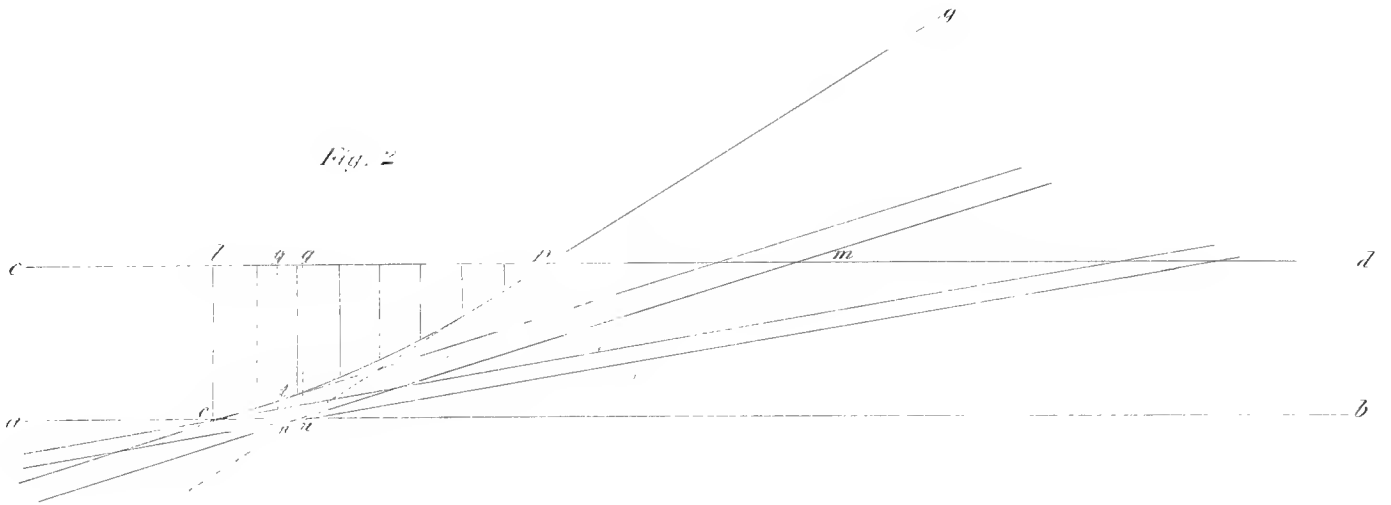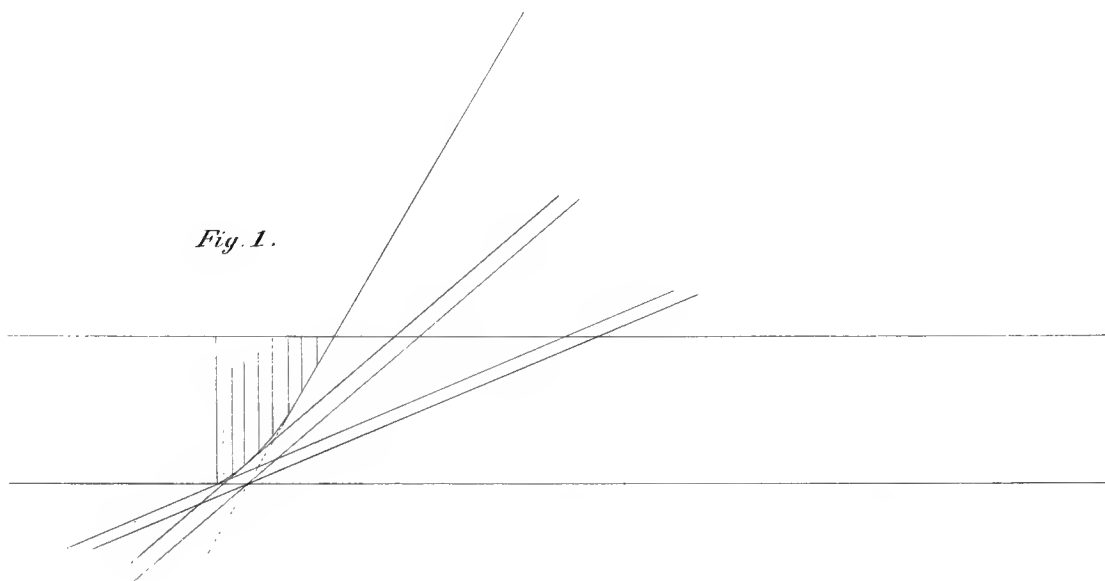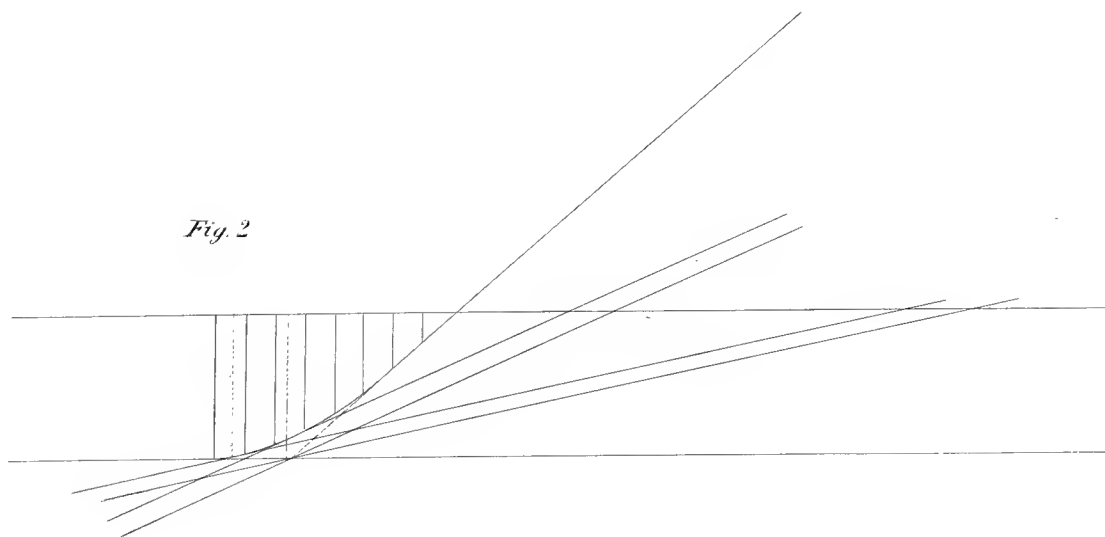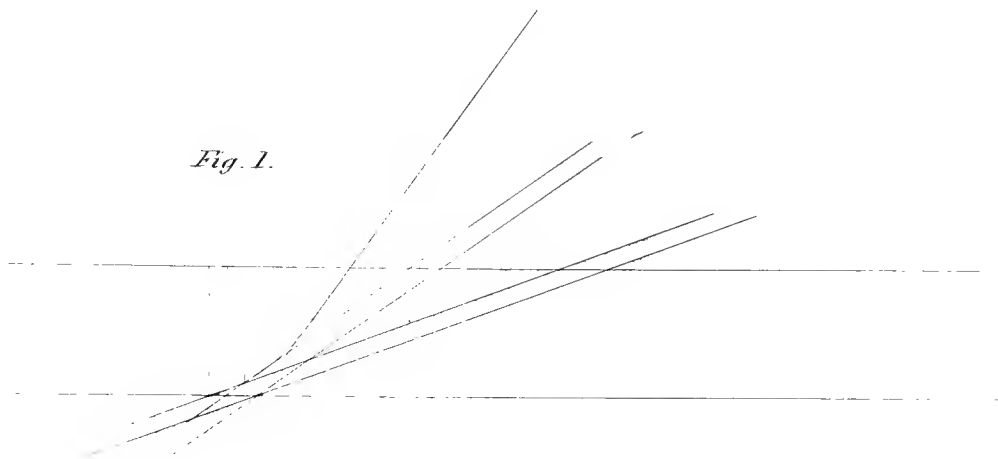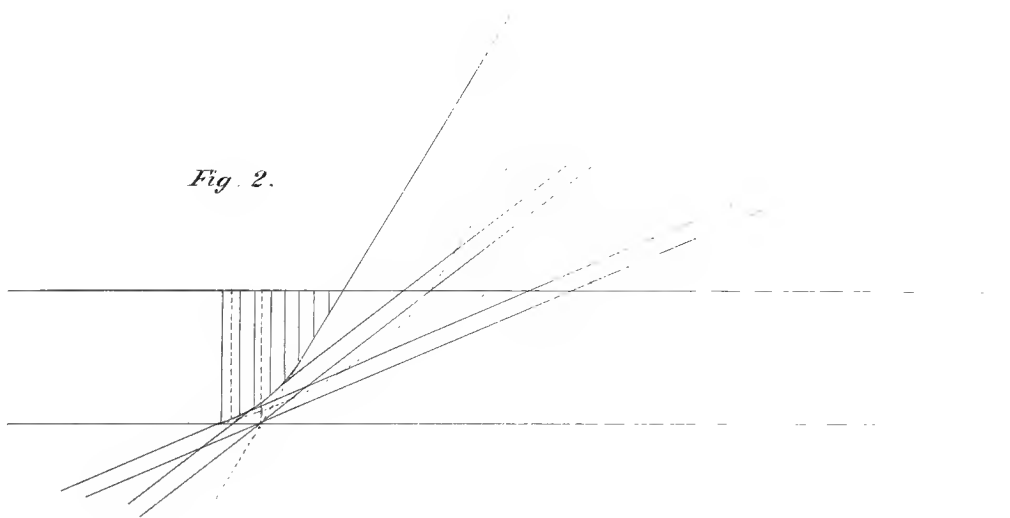
Fig. 1.
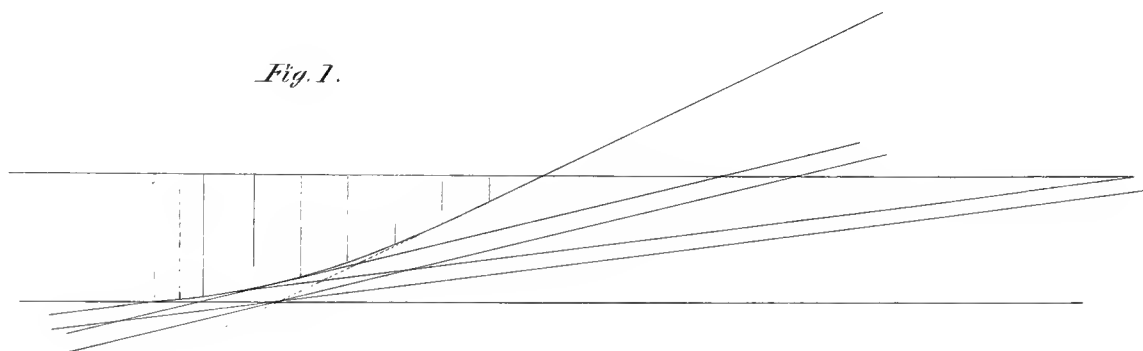
Fig. 2.
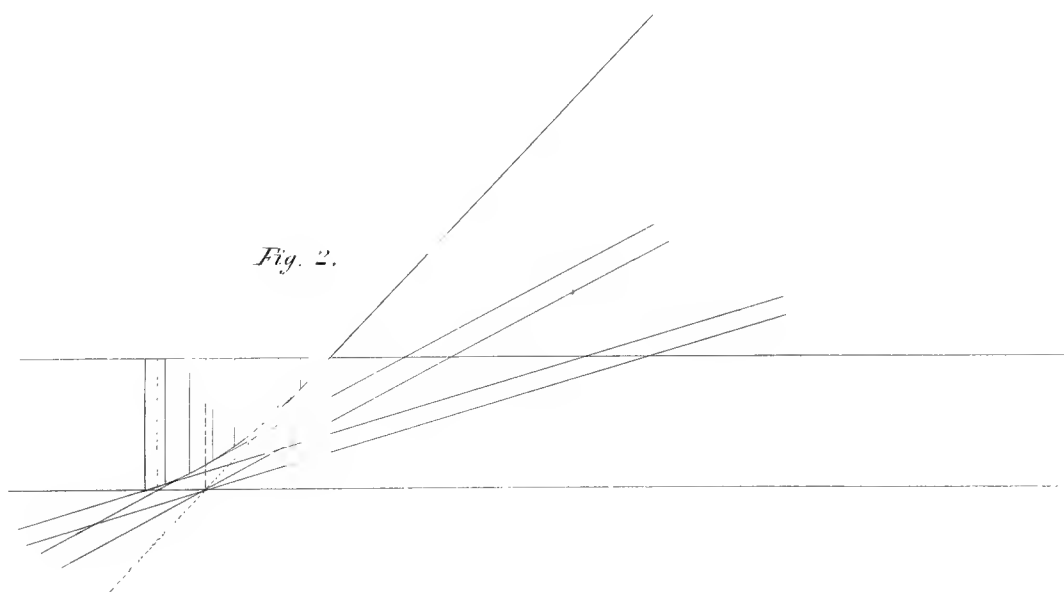
mean pressure during the first *sixteenth* part of that time was = 36264 pounds.

And the pressure must be still greater during the lower rates of velocity, amounting to, probably, 50000 pounds per inch; and this estimate is for *statical* pressure, the strain due to which, as will be shown further forward in this Report, must be considerably less than the actual strain, the rate of application of the force effecting the strain to which it subjects the resisting body, so far as even to double it, in the extreme case, or when the application of the force becomes instantaneous.

And it is believed that velocities equal to, if not greater than those now attained, might be secured, and the gun relieved from a large proportion of the strain to which it is now subjected, by the use of charges which would produce a more nearly uniform pressure upon the shot, during its passage through the bore of the gun.

The curves shown in Plates (5 and 6) were described while firing shot, and those on Plates (7 and 8) while firing shells. Weight of shot and sabot, 125 lbs; weight of shell and sabot, 102.25 lbs. Weight of charge in both cases, 18 lbs.

I am indebted for the transfer of the curves from the cylinders on which they were traced, to the sheets on which they now are, and for the drawings showing the lines of fracture of the guns, to Lieut. S. Crispin, Ordnance Department.

BURSTING GUN HEADS.

With a view to subject the metal of a gun to a mechanical test, as nearly similar in its action to that of gunpowder as possible, the head of gun No. 331 (cast hollow) was cut off to two feet in length, and reamed out to 10 in. diameter, with packing recesses of 2 in. wide by 1 in. deep.

The distance from out to out of these rings was 14.5 in., there being 4.5 in. from the end next the gun to the edge of one recess, and 5 in. from the sprue end to the outer edge of the other recess.

These recesses are shown at (*r*) in the accompanying drawing (Plate 9). A solid cylinder, with an opening or mortice (*m*) through it, of the same length as the head, and reduced 1.5 in. in diameter for a space of 10 inches along the middle of its length, was accurately turned, and inserted into the head.

This cylinder was also bored through its axis, and furnished with packing glands (g), one at each end, through which two pistons entered the cavity (m); one (p), called the penetrating piston, receiving the falling weight, and was thus driven into the cavity (m); the other (p'), called the indenting piston, had the indenting tool fitted into its outer end, and was forced out by the pressure produced by the entrance of the penetrating piston.

The packing recesses, and the glands around the piston, were supplied with sole leather packing rings. The head, with the solid cylinder and indenting piston inserted, was placed in a cast iron frame, of which the foundation (F) was a section, 18 inches long, of a 10-inch gun; and the bed piece (B) had a shank of the same length turned and fitted into (F), with an opening (O), to receive the specimen to be indented; also lateral arms, to which the upper portions of the frame were attached.

The frame around the head had cast iron upright slides bolted on to it, to guide the drop (a) in its descent upon the piston (p). The inner edges, and part of the sides of the slides, were planed, and recesses were planed in ledges, cast on to the sides of the drop, to fit and move freely on the planed parts of the slides, which were accurately adjusted in a vertical position.

The spaces (m) and (n) communicated with each other, and were, when the head was to be acted upon by the drop, filled with water.

In order to force the packing rings into their proper bearings, so as to prevent leakage, it was found to be necessary to attach a force pump to the head; this was done by drilling a small hole through the head, entering the interior at the upper edge of the lower packing recess, and attaching a wrought iron tube by means of a gland; the tube having a small valve adapted to the end that entered the head, opening inward, and being closed by pressure produced by the fall of the weight, thus relieving the pump attached to the other end of the tube from the aforesaid pressure, and preventing a reflux of water.

Everything being in position, the penetrating piston was removed, to allow the air a better chance to escape, and the pumps put in motion, and worked till the water reached the upper gland; the piston was then inserted, and the drop allowed to rest upon it. This weight at first caused the piston to penetrate, the water leaking past the packing rings.

But by working the pump the piston and drop were forced up, and a few falls of the drop were sufficient to force the packing rings to their proper

PLATE IX
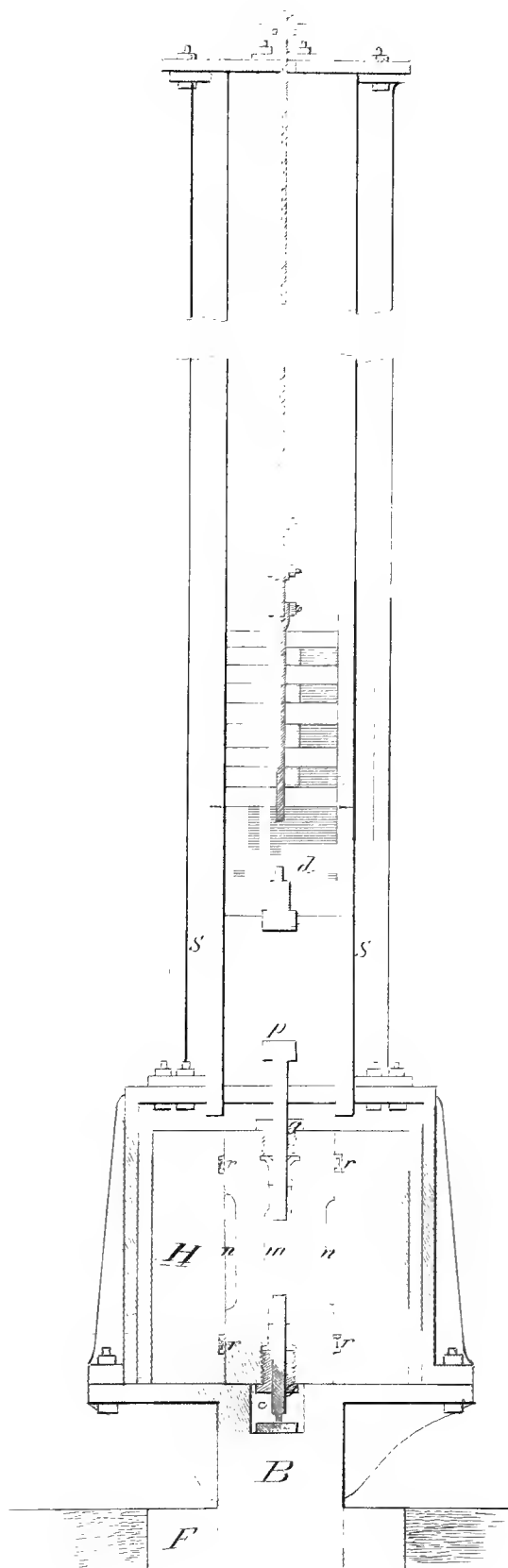
bearings, thus stopping all leaks. The first penetrating piston used, was one inch area of cross section, and the weight of the drop was 272 pounds.

Everything being ready, and in perfect working order, the weight was raised to a height of one foot, and let fall upon the piston, causing a penetration of 2.54 in., the weight rebounding as if it had fallen on an elastic spring. Repeated trials gave the same result.

The weight was then raised to a height of two feet, and let fall, producing a penetration of 3.85 in., and rebounding higher than before.

The weight was then raised to a height of four feet, and let fall, when the rebound threw the piston entirely out of the gland, the drop falling upon and bending it, the displacement being 4.7 in., with an estimated pressure of 3830 lbs. per square inch. These results rendered it evident that this piston was too small to produce displacement sufficient to break the head.

Another piston of 2.99 in. arc of cross section was made, and the glands reamed out to fit, the weight of the drop being increased to 1122 pounds.

With this arrangement, everything being in complete working order, and a piece of pure hammered copper being placed under the point of the indenting tool, and removed to a new position at each variation in the height fallen through by the drop, the results recorded in the following table were obtained :—

TABLE *showing the amount of indentation produced in pure copper, and the estimated pressure produced, by the fall of 1122 lbs. from different heights on a piston 1.953 in. diameter.*

Height.	Penetration	Total fall of Drop.	Displacement of water in cubic inches.	Estimated pressure per square inch.	Length of Indentation.	REMARKS.
1 ft.	2.47 in.	14.47 in.	7.399	4.503	.50 in.	The numbers un-
2	3.31	27.31	9.916	6.364	.64	der the head of
3	3.88	38.38	11.625	7.928	.72	indentation give
4	4.43	52.43	13.270	9.138	.77	the length of the
5	4.88	64.88	14.619	10.254	.895	indentation.

This weight of 1122 lbs. was thrown back by the elasticity of the metal and water, to a height nearly equal to that from which it had fallen, striking a number of blows of decreasing intensity before coming to a state of rest.

The rebound from a fall of 5 feet again threw the piston out of the gland; and although the slides were of sufficient length for a fall of 10 feet, owing to this cause, only 4 feet were available.

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It was thought that a portion of the elasticity manifested might be due to the air contained in the water; this was accordingly removed, and other water, that had been well boiled for an hour, substituted, and every precaution taken to insure the absence of air from the space intended to be filled with water.

The experiments were repeated to a fall of four feet, but with precisely the same results. The penetrations were measured by a graduated cylinder, so arranged that it could be pressed, or clamped as tight as desired, by a screw, but movable by the drop; the drop and cylinder stopping at the same time, the penetration was shown by the space passed over by the cylinder.

TABLE *comparing the* ACTUAL *with the* COMPUTED *pressures producing equal indentations in pure copper.*

Estimated pressures.	Length of indentation.	Actual pressure.	Length of indentation.
—	—	1000 lbs.	.21 in.
—	—	2000 "	.28
—	—	3000 "	.45
4503 lbs.	.50	4000 "	.53
—	—	5000 "	.60
6364 "	.64	6000 "	.68
7928 "	.72	7000 "	.72
9138 "	.77	8000 "	.78
—	—	9000 "	.84
10254 "	.895	10000 "	.891
—	—	11000 "	.952
—	—	12000 "	1.000
—	—	13000 "	1.040
—	—	14000 "	1.110

The indentations in the second column of the above table were made as before described.

The pressures in the first column were obtained by estimating the pressures per square inch due to, or caused by, the fall of the weight, and multiplying by the area of a cross section of the indenting piston.

The length of the penetrating piston was such, that the head would strike the gland before the point could come in contact with the inner end of the indenting piston.

The pressure produced by the falling weight was thus estimated:—

Let $a =$ area of cross section of penetrating piston,

$\quad W =$ weight of drop,

$\quad h =$ total height fallen through, in inches,

$\quad p =$ penetration of piston, and

$\quad p' =$ pressure per square inch, and

$\quad n =$ work done by the falling weight.

Then, since the work done in stopping the falling weight is equal to that due to the whole height fallen through, we have, supposing the pressure to increase directly as the penetration,—

$$n = a \ p' \int \frac{(p-x)}{p} \, d x \ (x) \text{ being variable between } o \text{ and } p \ ;$$

$$n = a \ p' \left(\frac{p \ x - \frac{x^2}{2}}{p} \right), \text{ and when } x = p, \text{ or } = \frac{a \ p \ p'}{2}, \text{ or,}$$

$\dfrac{a \ p \ p'}{2} = Wh$ and $p' = \dfrac{2 \ Wh}{a \ p} \ ;$ from which it appears, that for a given weight and fall, the pressure produced is inversely as the volume displaced, and the area of a cross section of the piston inversely as the penetration.

It was intended that all the indentations should be made with the same tool; but, on examining the tool before commencing the indentations recorded in the 4th column, it was found that a small piece had been accidentally broken out of the indenting edge since making those recorded in the 2d column. The tool was accordingly re-dressed, and made to conform as accurately as possible to the indentations already made.

With the tool thus prepared, the indentations recorded in the 4th column were made, the weights producing them being accurately determined by the testing machine. Some deductions should be made from the estimated weights in the 1st column, for the friction of the indenting piston against the packing, through which it moved.

The indentations recorded in the 2d column were made by *pressure* applied for only an instant of time, while those recorded in the 4th column were slowly made; and it is supposed that the indentation thus made would be greater for equal pressures than those made quickly, as the disturbed metal would have more time to adjust itself to its new condition.

That the indentations recorded in the 2d column were produced by *pressure*,

and not by a blow (as might be inferred from the mode of producing them), was clearly proven, by comparing the indentation produced by a single fall of the drop with one caused by repeated falls of the same weight from the same height, the indentations thus produced and compared being precisely equal.

Making deductions for friction and time, as above indicated, the correspondence between the estimation and actual pressure due to equal indentations is sufficiently accurate to leave no doubt of the truth of the formula by which the estimated pressures were computed.

In order, as far as practicable, to prevent the bounding out of the penetrating piston, the quantity of water was so regulated, that the head of the piston, at its greatest penetration, was only about one inch from the gland.

A pressure of 9000 lbs. being the greatest practical pressure attainable with this weight, and it being supposed that an almost indefinite number of blows of this intensity would be required to break the head, and the advanced state of the season not affording time for a further increase of weight, the experiment was discontinued.

The apparatus is all carefully preserved, and the experiment may be renewed at any time.*

On the supposition that the increase of capacity, caused by the compression of the solid cylinder, and contained water, is equal to that caused by the elongation of the metal of the gun head, a displacement of 14.619 cubic inches, the greatest produced, would give an elongation of .0032 in. per inch on the interior surface of the head, which is just double that given by Mr. Hodgkinson as the elongation of cast iron at the rupturing strain, viz.: $\frac{1}{800}$ of its length, or .0016 of its length.

How much of the increased capacity is due to compression of the solid cylinder and contained water, and how much to the elongation of the metal of the head, cannot, from these experiments, be accurately inferred.

The elongation per inch, at rupture, of the metal of the gun from which this head was taken, as determined by bending specimens, is .011678. It would therefore appear that the metal of the gun head has only been extended to a little over one-fourth of its capacity; and, supposing equal increments of extension to be produced by equal increments of pressure, a force of about 40000 pounds per inch would be required to break the head;

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* This apparatus has since been destroyed by the burning of the Fort Pitt Foundry, where the experiments were made.

and I have no doubt it would require a force of that intensity, acting only for an instant, to break it; while one of 30000 pounds per inch, acting for any considerable length of time, would doubtless produce the same effect.

Of the Effects of different rates of Application of Straining Forces upon the Bodies to which they are applied.

The following remarks are in exemplification of this subject, as treated by Mr. Robert Mallet, in his valuable work "On the Construction of Artillery."

In estimating the effect of any force upon an elastic or yielding material to which it may be applied, the rate of application, or the time which elapses from the instant when the force begins to act till it attains its maximum, should not be neglected.

This effect may be illustrated by supposing the case of an elastic body, as a steel plate, or a slip of elastic wood, firmly secured at one end, in a horizontal position, thus: let the elastic body $(a\,b)$ be firmly secured in the
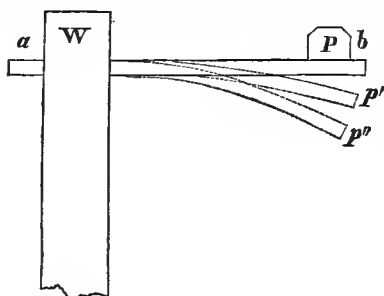
wall (W), and let the weight (p) be placed slowly upon the unsupported end, the resisting body will be depressed to a position (p') when the resistance will equal the weight (p); this will be the position of statical equilibrium for this particular weight (p).

But if the weight (p) be removed, and the resisting body $(a\,b)$ allowed to resume its horizontal position, and the weight be placed in contact with, but not resting upon, the upper surface, and suddenly let go, $(a\,b)$ will be again depressed, the weight (p) being in excess of the resistance until the position (p') of statical equilibrium be reached; from this point the resistance will be in excess of the weight, and the velocity of (p) will be constantly diminished, and finally become (0), at (p''); and if the elasticity of $(a\,b)$ be perfect, the position (p') will be intermediate between (p) and (p''), and the body $(a\,b)$ consequently subjected to a strain just double as great as that of statical resistance to the weight (p).

On reaching the position (p''), the elastic force of $(a\,b)$ being in excess of (p), will cause $(a\,b)$, with its load (p), to rise, and return to its original position (p); and in case of perfect elasticity, and the absence of all other disturbing forces, $(a\,b)$ would continue to vibrate between the positions (p) and (p''); but owing to imperfect elasticity, and atmospheric resistance, $(a\,b)$

will vibrate with a constantly decreasing extent of excussion, until it finally stops at the position of statical equilibrium (p').

Now, if (p) had been restrained between the positions (p), and (p'), and only abandoned to the full force of gravity at some point between these two, then (*a b*) would have arrived at the position of statical equilibrium with a less velocity than in the previous case, and would have stopped at some point between (p') and (p'').

From which it appears that the more slowly the straining force is applied, the less will be the velocity with which the resisting body will reach the position of statical equilibrium, and the less distance will it be forced beyond that position, by the momentum of the mass in motion; and, consequently, the less will be the strain beyond that due to statical equilibrium.

This principle is applicable to all intermittent strains; it being known that a bridge suffers greater strain from the rapid transit of a train of cars, than from one of the same weight, but at a lower speed, and if the whole train were suspended over the bridge, in contact with the rails, and suddenly abandoned to the force of gravity, the strain produced would be double that of a very slowly passing train of the same weight.

So it is, to a certain extent, in the discharge of cannon; for with equal ultimate pressures of gas per square inch of surface, that powder will be most severe upon the gun which attains this pressure in the shortest period of time after ignition.*   The fulminating powders, being almost instantaneous, develop strains almost double as great as those due to the statical pressure of the gas evolved, and hence their bursting tendencies; and, the more rapid the combustion of any charge of powder (*cacteris paribus*), the greater will be the strain upon the gun in which it is burned.

* My views on this subject have been modified since writing the above, and will be given at the end of these Reports.

Of the Various kinds of Strain to which a Gun is subjected at each Discharge.

(FIG. 1.)
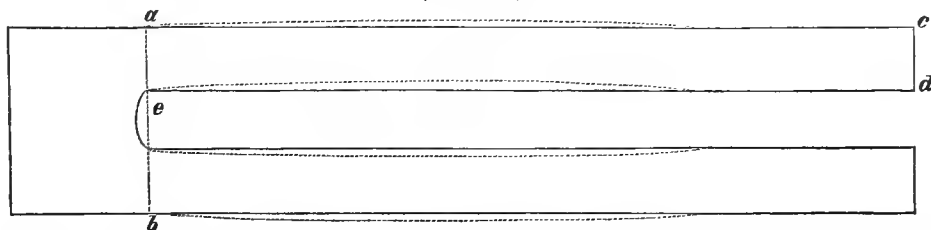
There are, first, a *tangential strain*, tending to split the gun open longitudinally, and being similar in its action to the force which tends to burst the hoops or bands upon any expanding substance.

2d. A *longitudinal strain*, tending to pull the gun apart in the direction of its length; this tendency is greatest at or near the bottom of the bore (*a b*), and diminishes with the mass of that portion of the gun in front of any assumed point, being (0) at the muzzle.

These strains both tend to increase the volume of the metal to which they are applied.

3d. A *strain of compression*, exerted from the axis outward, tending to crush the truncated wedges of which a unit of length of the gun may be supposed to consist, to give a cross section of the gun this appearance, and to diminish the thickness of the metal to which it is applied.
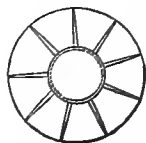
4th. A *transverse strain*, tending to break transversely, by bending outward the staves of which the gun may be supposed to consist, and to give to a longitudinal section the appearance shown by the dotted lines.   (Fig. 1.)

Tangential Strain.

On the supposition that the area of a cross section of the gun remains the same before and during the application of the straining force, the resistance which a gun one calibre thick is capable of offering to a central force has been shown ("Reports of Experiments on Metals for Cannon," page 210,) to be $= \dfrac{A}{r} - \dfrac{A}{R}$, in which $a =$ tensile strength of r^2.

The general expression, for this resistance, per unit of length, being $\dfrac{(r^2}{r} s - \dfrac{r^2 s}{R} = \dfrac{R\, r^2\, s - r^3\, s}{R\, r}$, in which R and r represent the radii of the exterior of the gun, and of the bore, and (s) the tensile strength per square inch of metal.

The rupturing effort per unit of length, in terms of radius of bore and pressure, per inch, $= p\,r$; and the tendency to rupture will $=$ rupturing effort, divided by the resistance which the gun can offer $= \dfrac{p\,r}{\dfrac{R\,r^2s - r^3s}{R\,r}} =$

$\dfrac{R\,r^2 p}{R\,r^2s - r^3s} = \dfrac{R\,p}{R\,s - r\,s}$; and when $R = 3r$, or the gun is one calibre thick, the tendency to rupture $= \dfrac{3}{2}\dfrac{p}{s}$, or where none but the tangential resistance is offered, rupture will ensue, when the pressure per square inch exceeds two-thirds of the tensile strength per square inch.

Longitudinal Strain.

If the bore of the gun terminate in a hemispherical bottom, the maximum tendency to rupture, by a longitudinal strain, will be at, or a little in rear of, the junction of the cylinder and hemisphere of the bore.

And it is believed that the resistance which the gun can offer to this force will differ but little from that which a hollow sphere, of the same quality of metal, whose interior and exterior diameters are equal to those of the gun, would offer to a bursting force; and that the law of diminution of strain, from the interior outward, will be the same for any central section of the sphere, as for a cross section of the gun.

To obtain an expression for this resistance, let (r) and (R) represent the interior and exterior radii of the gun, and (s) the tensile strength per square inch of metal, and (x) any variable quantity between (r) and (R).

Then $s\,2\,\pi\,x\,d\,x$ would express the resistance which an elementary shell, whose radius $= x$, would offer, if the strain were uniform throughout the entire thickness.

But the strain is supposed to be a maximum when $x = r$, and to diminish as the square of the distance from the centre, or axis, increases; therefore the expression $s\,2\,\pi\,x\,d\,x$ must be multiplied by $\dfrac{r^2}{x^2}$, in order to express the elementary resistance, under the law of diminution of strain, due to any value of (x) between (r) and (R).

The elementary expression, therefore, becomes $s\,2\,\pi\,\dfrac{r^2}{x^2}x\,d\,x = s\,2\,\pi\,r^2\dfrac{d\,x}{x}$; the integral of which, or the total resistance, will $= s\,2\,\pi\,r^2$, Nap. log. x; or, integrating between the limits $x = r$ and $x = R$, we have the

total resistance $= u = s\, 2\, \pi\, r^2$ (Nap. log. R — Nap. log. r) $= 2\, s\, \pi\, r^2$ Nap. log. $\frac{R}{r}$. Now when $R = 3\, r$, or the gun is one calibre thick, the Nap. log. of $\frac{R}{r}$ = Nap. log. of 3 = 1.0986, and the total resistance $= 2\, \pi\, r^2\, s \times 1.0986$.

But the rupturing effort $= \pi\, r^2 p$, (p) representing the pressure per square inch of gas at the bottom of the bore.

The tendency to rupture will therefore $= \dfrac{\pi\, r^2\, p}{2\, \pi\, r^2\, S \times 1.0986}$; or, in round numbers, after dividing by $\pi\, r^2$, it will $= \dfrac{p}{2\, S}$; or the gun would be three times as strong longitudinally as tangentially, if the bursting effort were resisted by its tangential strength alone.

That the tendency to rupture, from the action of this force, is greater at, or a little in rear of the junction of the hemisphere and cylinder of the bore, than forward of that point, is shown by the following considerations, viz:—

The effect of the pressure upon that portion in rear of this point, is to crush the truncated pyramids, of which that portion of the gun may be supposed to consist, and to give to a central section of the sphere, after rupture, the same appearance as a cross section of the cylindrical portion of a gun, of compressible material, after rupture; while no transverse cracks would be found in the cylindrical part of the gun, from this cause.

And since the force is all applied at the inner surface of the gun, the strain will be greatest at that surface, and will diminish directly as the distance from the axis increases.

The expression for the elementary resistance would therefore $= s\, 2\, \pi\, r\, d\, x$, and its integral, or the total resistance, would $= u = s\, 2\, \pi\, r\, x$. And integrating between the limits $x = r$, and $x = R$, we have $u = s\, 2\, \pi\, r\, (R - r)$. Then if the gun be one calibre thick, R will $= 3\, r$, and $u = s\, 2\, \pi\, r\, (3\, r - r)$ $= s\, 4\, \pi\, r^2$. And the tendency to rupture will $= \dfrac{p\, \pi\, r^2}{4\, S\pi\, r^2} = \dfrac{p}{4\, S}$; or the tendency to break at or a little in rear of the junction of the cylinder and hemisphere of the bore, is twice as great as at any point forward of that position, from the action of the longitudinal force alone.

The tangential and longitudinal strains are in directions at right angles to each other; and hence, probably, neither affects the ability of the metal to resist the other, while the compressibility of the metal tends to diminish its capacity to resist either.

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Crushing Force.

Without attempting to give an algebraic expression for the rupturing effect of this force, yet its tendency is known to be to diminish the thickness of metal in the gun, and thus to increase the diameter of the bore, beyond that which would result from the action of the transverse and tangential forces alone.

This force diminishes from the bore outward, while the area of resistance increases. The effect of this, upon a compressible truncated wedge, would be to change its form from that of Fig. (*a*) to that of Fig. (*b*).

(FIG. *a*.) (FIG. *b*.)
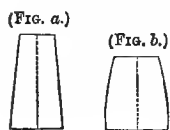
And the appearance of a cross section of the gun after rupture would be that of Fig. (*C*).
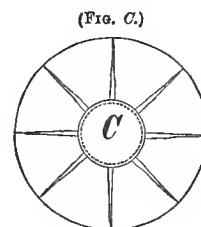
(FIG. *C*.)

If the metal were incompressible, the appearance of a cross section of the gun after rupture would be that of Fig. (*C′*), and no enlargement of the bore would result from the *crushing* of the metal; and any enlargement caused by the action of a central force would be accompanied by an equal enlargement of the exterior diameter of the gun; and hence the strain upon the metal, at the inner and outer surfaces of the gun, would be inversely as the radii of those surfaces, instead of inversely as their *squares* (as in the case of compressible metal).

(FIG. *C′*.)
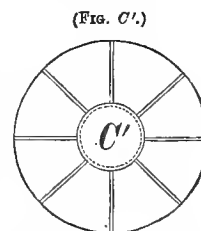
The expression for the total resistance per unit of length would be, for a gun one calibre thick, (*r s* Nap. log. 3,) or, in round numbers (*r s*), instead of ($\frac{2}{3}$ *r s*), as in the case of compressible metal.

Perfect incompressibility would therefore bring into action one-third more tangential resistance than the same metal without it would be capable of offering to a central force.

It would therefore appear that, all other qualities being equal, that metal which is least compressible will offer the greatest resistance to a central force.

Of Resistance to Transverse Strain.

In estimating the resistance which a gun can offer to a tendency to transverse rupture, it will be more simple to regard the gun as composed of staves, firmly secured at their ends, the rear ends being supposed to be secured to a central cylinder, or "breech-pin;" and in this case it will only be necessary to consider a single stave, as all others of equal width and length would be subjected to similar and equal strain.

Let us, therefore, consider the action upon a single stave, whose interior breadth is one inch; and,

FIG. 2.
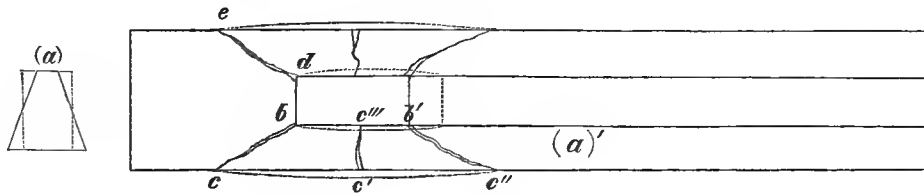
if the gun be one calibre thick, the exterior breadth of this stave will be 3 inches; and we shall be something below the actual resistance which the stave can offer, if we consider it as of rectangular section of 2 inches in breadth; this is apparent from inspection of Fig. (*a*).

Let (*a*) be the stave acted upon by the pressure of gas along its inner surface, and suppose the pressure to be applied between the points (*b*) and (*b'*). Now this stave is secured at both ends, and the rupturing force equally distributed along its length between the points of support, and suffers a tendency to rupture at three points, as shown in Fig. (2) by the lines (*b c*), (*c''' e'*), and (*b' c''*).

The formula for the resistance which a bar thus strained can offer, is $w = \dfrac{12\ S'\ b\ d^2}{l}$ in which w = breaking weight, b = breadth of bar, d = depth of bar, (l) = length of bar, and S' = weight required to break a bar of same metal one inch square, firmly secured at one end, when applied at one inch from the point of support.

Now if (p) = pressure of gas per square inch, the whole pressure on the stave will = $p\ l$, and the tendency to rupture will be = $\dfrac{p\ l}{\dfrac{12\ S'\ b\ d^2}{l}} = \dfrac{p\ l^2}{12\ S'\ b\ d^2}$.

It thus appears that the tendency to transverse rupture increases, as the

square of the length of the bore under pressure, and that the resistance offered to this kind of strain increases as the square of the thickness of metal.

But for equal weights of powder, a given interior reduction of (d) gives a much greater corresponding reduction of (l); thus, in the 10-in. Columbiads, by removing the chamber, and terminating the bore by a hemisphere, we diminish (d) by one inch, the corresponding diminution of (l) being 3.5 inches.

The resistance offered by the transverse strength of the staves acts in concert with the tangential resistance; and when the length of bore under pressure is such that the increase of its diameter due to the bending of the staves, plus that due to the compression of the metal at the moment of rupture, shall be equal to that which it would attain at the same moment, from the action of the tangential strain alone, then will the resistance to rupture be equal to the sum of the transverse and tangential resistances.

This can only occur for one particular length of surface pressed; and, for any greater length, the staves would require to be bent out beyond the breaking diameter for the tangential resistance, before reaching their breaking strain; and the transverse resistance would only be equal to the pressure necessary to bend the staves out to the position of tangential rupture, minus the compression of the metal.

And the tangential resistance would be overcome, and the gun split longitudinally, before the transverse resistance would be brought fully into action.

The effect of the crushing force on compressible metal being to prevent the development of the transverse resistance, in the same manner as it did that of the tangential resistance, to diminish the length of bore required to develop the joint action of these two resistances, and to diminish the amount of aid which the transverse resistance can bring to the tangential for any greater length of bore.

And when the length of surface pressed becomes less than that which develops the joint action of both resistances, the diameter due to transverse rupture will be less than that due to tangential rupture, and transverse rupture would first ensue; or, what is more probable, in guns of any considerable thickness of metal, rupture will occur by splitting through the

breech, or by forcing the rear ends of the staves outward, causing rupture along the lines (*b c*) and (*d e*), Fig. (2).

In all practical cases, the length of stave will exceed that of surface pressed, the strain produced not terminating abruptly at the outer end of this surface, but extending forward to some distance beyond that point.

Nor will the rear ends of the staves remain absolutely fixed, as the diameter of the breech pin will be enlarged by the force which presses the rear ends of the staves outward, thus developing tangential resistance at this point, when enlargement of bore from transverse resistance will be (*o*).

And in chambered guns rupture ought to begin at the junction of the taper and chamber, since a given increase of diameter of bore involves an equal increase of diameter in the chamber, while the circumference of a section of the bore is greater than that of a section of the chamber, in the ratio of their diameters.

The strain upon the interior of the chamber being greater than that upon the interior of the bore, in the proportion of the diameter of the bore to that of the chamber.

This supposes the metal to be incompressible; and the more compressible the metal, the more will the strain upon the chamber exceed this proportion, owing to the compression of the metal around the chamber, and within the continuation of the surface of the bore.

And the shorter the taper, for a given difference in diameter of bore and chamber, the greater will be the probability of rupture at the junction of the taper and chamber. The body of metal around the chamber, and within the continuation of the surface of the bore, will doubtless relieve the bore, at its junction with the taper, from a portion of the strain to which it would otherwise be subjected, so long as *it* remains unbroken.

But we must not suppose the gun to be as strong after the *rupture* of this body of metal as it would have been had it been *bored* out originally; for the line of rupture of this metal becomes the weakest part of the gun, along which the effects of both strain and vibration are concentrated, causing a much more rapid destruction of the gun after than before the formation of a fissure.

It hence appears that the maximum pressure should be confined to the shortest length of bore possible, and that the use of chambers in guns of large calibre is a custom of very doubtful propriety, since they always increase the

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length of the bore subjected to the maximum pressure, and, it is believed, cause rupture to *commence* sooner than it would otherwise do.

These conclusions appear to be sustained by practical results; for in all the Columbiads that I have seen broken, every one was more or less cracked in the chamber and taper, the cracks being longest and most numerous near their junction; while the bore adjoining the outer end of the taper, and which must have been subjected to an equal pressure, has never been observed to be cracked.

Resuming the expression for the transverse tendency to rupture $\dfrac{p\,l^2}{12\,S'\,b\,d^2}$, and supposing the transverse strength of iron to be one-fourth the tensile, or $S' = \dfrac{S}{4}$; and substituting for S' its value $= \dfrac{S}{4}$, we have $\dfrac{4\,p\,l^2}{12\,S\,b\,d^2} = \dfrac{p\,l^2}{3\,S\,b\,d^2}$; then, supposing $l = 20$ in., $b = 2$ in., and $d = 10$ in., we have tendency to transverse rupture $= \dfrac{400\,p}{600\,S} = \dfrac{2\,p}{3\,S}$; or the transverse strength alone, supposing tensile strength $= 30000$ pounds per inch, would resist a pressure of 45000 pounds per inch for two calibres in length, of a 10-inch gun, if it could be brought fully into action. This, for reasons already given, cannot, however, be done; but the transverse is doubtless a powerful auxiliary to the tangential resistance for short lengths of bore, and where the pressure is greatest.

The expression $\dfrac{3\,p}{2\,S}$ for the tendency to rupture, when the tangential force alone is considered, showing that, for a tensile strength of 30000 pounds per inch, rupture would be produced by any pressure above 20000 pounds per inch, which must be far below that to which guns of large calibre are subjected.

A pressure of 20000 lbs. having been reached in a 6-pdr. gun with 1.5 lbs. powder and one shot, and supposing the pressure to increase with the diameter of bore, would give over 50000 lbs. per inch on a 10-inch gun.

When the bore terminates in a hemisphere, the tendency to rupture that portion in rear of the junction of the cylinder and hemisphere, from the pressure upon the interior of the latter alone, will equal the tendency to rupture from the action of the longitudinal force alone $= \dfrac{p}{2S}$.

The tendencies to rupture the different resistances, each considered as independent of all others, will, therefore, be as follows, viz. :—

Tangential $=$ . . . . $\dfrac{3\,p}{2\,S}$

or rupture will ensue when $3\,p > 2\,S$.

Longitudinal $=$ . . . . $\dfrac{p}{2\,S}$

or rupture will ensue when $p > 2\,S$.

Resistance to pressure on interior of hemisphere $=$ $\dfrac{p}{2\,S}$

or rupture will ensue when $p > 2\,S$.

Transverse $=$ . . . . $\dfrac{2\,p}{3\,S}$

or rupture will ensue when $2\,p > 3\,S$.

It thus appears that the tendency to rupture is greater with the tangential resistance acting alone, than with any other; and for lengths above two, or perhaps three calibres, the tangential resistance may be said to act alone; as the aid derived from the transverse resistance will be but trifling for greater lengths of bore. But for lengths of bore less than two calibres, this resistance will be aided by both the transverse and the resistance of the hemispherical breech, which causes this latter to become, probably, the weakest part of this portion of the gun, with the use of our present quick powder.

Every gun should, therefore, have sufficient thickness of breech to cause rupture to take place (if at all) along the lines (b c) and (d e) Fig. 2, instead of splitting through the breech; and after this point has been attained, any additional thickness of breech will add nothing to the strength of the gun.

This investigation shows the gun to be strongest at, or near, the bottom of the bore; and that its strength diminishes rapidly as the length of the bore increases, to a certain point (probably not more than 3 calibres from the bottom of the bore), where, for equal thickness of metal, its strength becomes sensibly uniform.

Therefore, in order that the gun may be equally strained in all its parts in firing, or that the maximum velocity of shot for a given maximum pressure may be obtained, it would appear that the charge should consist of a small portion of quick powder, whose expansive force would be rapidly developed, the remainder of the charge being so constituted that the evolution of gas should be proportional to the space passed over by the shot; and a charge

thus constituted would give the maximum velocity of shot attainable, with a given length of bore and thickness of metal.

Bursting Effects of Different Weights of Powder and Shot in Guns of Different Calibre.

Assuming, with Hutton, that the quantities of action due to the expansive force of different weights of the same quality of powder are proportional to those weights, we have the proportion $\dfrac{W v^2}{2 g} : \dfrac{W' v'^2}{2 g} :: w : w'$; in which (W) and (W') represent the sums of the weights of both powder and shot; (w) and (w') the weights of powder, (v) and (v') the velocities of the common centres of gravity of the powder and shot, and (g) the force of gravity.

Now the mean pressure, or that which, acting with uniform intensity along the distance through which the common centre of gravity of the powder and shot passes, in acquiring the velocity (v), will $= \dfrac{W v^2}{2 g l}$ (l), being the distance above named, or length of bore of the gun.

Now, supposing the guns to be equal in length of bore, the mean pressures will be to each other as $\dfrac{W v^2}{2 g l} : \dfrac{W' v'^2}{2 g l}$, or as $W v^2 : W' v'^2$. And since the pressure per square inch is equal to the whole pressure upon the shot and charge, divided by the area of the surface pressed, the pressures per square inch will be to each other as $\dfrac{W v^2}{\pi r^2} : \dfrac{W' v'^2}{\pi r'^2}$, or as $\dfrac{W v^2}{r^2} : \dfrac{W' v'^2}{r'^2}$ (r) and (r'), representing the radii of the bores.

But the bursting effort, per unit of length, equals the pressure per square inch, multiplied by the radius of the bore, and is therefore $= \dfrac{r\, W v^2}{r^2}$; or the bursting efforts upon the two guns will be to each other as $\dfrac{r\, W v^2}{r^2} : \dfrac{r'\, W' v'^2}{r'^2}$, or as $\dfrac{W v^2}{r} : \dfrac{W' v'^2}{r'}$.

But the tendency to rupture, of any force, equals its rupturing effort, divided by the resistance which the body to which it is applied is capable of offering.

This resistance has been shown (page 43) to be $\dfrac{R\, r^2 S - r^3 S}{R\, r}$.

The tendencies to rupture will therefore be to each other as $\dfrac{\dfrac{W\,v^2}{r}}{\dfrac{R\,r^2\,S - r^3\,S}{R\,r}}$:

$\dfrac{\dfrac{W'\,v'^2}{r'}}{\dfrac{R'\,r'^2\,S' - r'^3\,S'}{R'\,r'}}$: or as $\dfrac{R\,W\,v^2}{R\,r^2\,S - r^3\,S}$: $\dfrac{R'\,W'\,v'^2}{R'\,r'^2\,S' - r'^3\,S'}$, or as $\dfrac{R\,W\,v^2}{r^2\,S\,(R-r)}$: $\dfrac{R'\,W'\,v'^2}{r'^2\,S'\,(R'-r')}$.

And substituting for $W'\,v'^2$ its value derived from the proportion $W\,v^2 :$
$W'\,v'^2 :: w : w'$, we have the tendencies to rupture as $\dfrac{R}{r^2 S\,(R-r)}$: $\dfrac{R'\,w'}{r'^2 S'\,(R'-r')\,w}$.

And supposing the quality of the metal to be the same in both cases, these tendencies will be to each other as $\dfrac{R}{r^2\,(R-r)}$: $\dfrac{R'\,w'}{r'^2\,(R'-r')\,w}$.

Now, in comparing the bursting efforts of the charges fired from the ten-inch (10-in.) Army gun with those of the charges fired from the eleven-inch (11-in.) Navy gun, we have for the Army gun $R = 15.5$ in., $r = 5$ in., and $w = 18$ lbs.; and for the Navy gun $R' = 16$ in., $r' = 5.5$ in., and $w' = 15$ lbs.

Therefore $R - r = R' - r'$, and the bursting tendencies will be to each other, supposing the quality of metal the same in both cases, as $\dfrac{R}{r^2}$: $\dfrac{R'\,w'}{r'^2\,w}$; or, in round numbers, as $14 : 10$.

Again, if we reduce the weight of powder and shot in both cases to a cylindrical shape, the areas of their bases being equal to those of sections of the bores, the heights of the cylinders of powder will be 6.33 in. for the 10-in. Army gun, and 4.41 in. for the 11-in. Navy gun; and the heights of the cylinders of metal will be 6.10 in. for the Army gun, and 5.5 in. for that of the Navy.

Each square inch of the surface of the projectile pressed in the Army gun, will, therefore, have 6.33 cubic inches of powder in its rear, and 6.10 cubic inches of metal in front.

While, in the Navy gun, the powder in rear of each square inch of surface pressed is 4.41, and the metal in front 5.5 cubic inches.

It would, therefore, seem that the pressure per square inch of surface in the Army gun is greater than that in the Navy gun, in the same proportion as the pressure produced by firing a gun of one inch area of section of bore, with 6.33 cubic in. of powder, and 6.10 in. of metal, to that produced in firing the same gun with 4.41 cubic inches of powder, and 5.5 of metal.

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There can, therefore, be no doubt that the maximum pressure per square inch is greater in the Army than in the Navy gun. The length of bore to which the maximum pressure is applied, and the length of time during which the pressure in the bore exceeds the *mean* pressure, will also be greater in the Army gun than in that of the Navy.

The difference in endurance, due to a given difference in the bursting tendency at each fire, is not known; but it is believed that the difference in bursting tendency at each fire, which the foregoing reasoning indicates as existing between the two guns, will go far to account for the difference in their endurance. The tangential resistance alone has been here considered. To include the transverse resistance, would show a still greater difference in bursting tendency.

The foregoing conclusions are based upon the supposition that the maximum pressures will be *proportional* to the mean; which is not known, that I am aware of, to be strictly true.

The *mean* will differ less from the *maximum* pressure as the length of the bore becomes shorter, for a given charge of powder, down to the point where the maximum pressure is reached.

The position of this point will depend upon the weights of the shot and charge, and upon the rapidity of combustion of the charge; and the more rapid the combustion, and the heavier the shot, the less distance will it have moved from its original position before reaching that of maximum pressure.

The maximum pressure itself, other things being equal, will increase with the rapidity of combustion, being an absolute maximum for the kind of charge used, when the combustion is instantaneous; in which case the maximum pressure would be reached before the shot has moved at all. And the maximum pressure per unit of surface would no longer depend upon the weight of either shot or charge, but upon the difference in volume of the gas from that of the charge from which it was evolved.

Not so, however, with the bursting effects, as they would increase with the weight of both shot and charge; the weight and shape of the charge regulating the length of bore subjected to the maximum pressure, and the weight of the shot the time during which pressure, differing but little from the maximum, is applied.

This investigation is offered as a *probable* explanation of the difference in endurance of guns cast and cooled in the same manner, made from iron of

the same qualities, treated in nearly the same manner, and differing but slightly in quality, in the guns themselves.

Probability, however, is not *knowledge*, but it is the *most* that can now be offered, as well upon this as upon many other points of equal importance.

We do no*t know*, for example, what qualities of iron are necessary to make the best gun ; nor, if we did, do we know how, from any of its ores, constantly to produce iron which shall possess those qualities.

We do not *know* whether guns should be cast hollow or solid, nor the proper rate of cooling for either mode of casting.

We do not *know* the best exterior model for guns, nor whether those of large calibre should be made with or without chambers.

We do not *know* the effects of time upon the endurance of guns, — whether they are better when *new*, or after they have lain unused for any given length of time.

We do not *know* the maximum statical pressure due to a given weight of powder and shot, nor how much the rate of combustion of the charge, or the rate of application of the force, causes the bursting tendency to exceed that due to the *statical* pressure.

We do not *know* the difference in endurance due to a given difference in bursting tendency at each discharge, nor what weight of projectile is equivalent in bursting tendency to a given weight of powder, nor the difference in endurance due to a given difference in thickness of metal.

We do not *know* the difference in bursting tendency due to a given difference in temperature of the same charge of powder at the moment of ignition.

Nor do we *know* the proper constitution of charge in order to produce a given velocity of projectile with the minimum bursting tendency upon the gun.

And it is believed that the true interests of the country would be promoted, in a military point of view, by entering, at as early a period as practicable, upon a series of experiments which would supply positive knowledge in place of probability in *some*, and positive ignorance in *many other* points of the utmost importance to the national defence; for it is better that millions should be expended in time of peace, and from an overflowing treasury, than that a single gun should burst in action.

<div align="center">(Signed,)   T. J. RODMAN, *Capt. of Ord.*</div>

To Col. H. K. CRAIG, *Ordnance Office, Washington, D. C.*

ALLEGHANY ARSENAL, *January 30th,* 1857.

I subscribe to those facts and opinions, detailed in the above Report, which have reference to the casting, cooling, proving, and other operations with the trial guns, which were enjoined on me to observe and report upon, in conjunction with Capt. Rodman, by virtue of instructions from the Ordnance Department relative to the matter, dated August 18th, 1856.

Also, from the conflicting and unsatisfactory results which have been obtained in the recent trials with Columbiads, I am of the opinion that we do not possess the requisite knowledge to manufacture guns of these calibres which can be relied upon for any given number of fires.

I, therefore, fully concur in Capt. Rodman's suggestion, that the casting of service Columbiads be suspended for the present, and that a series of experiments be instituted to furnish the requisite data for the fabrication of reliable cannon of these calibres.

<div style="text-align:right">S. CRISPIN, Lieut. of Ord.</div>

To Colonel H. K. Craig, }
    Ordnance Office, Washington City, D. C. }

Alleghany Arsenal, January 30th, 1857.

REPORT

RELATIVE ENDURANCE OF GUNS

MADE FROM THE SAME IRON, BUT MELTED IN FURNACES OF DIFFERENT CONSTRUCTION.

ALSO,

OF GUNS MADE FROM THE SAME IRON,
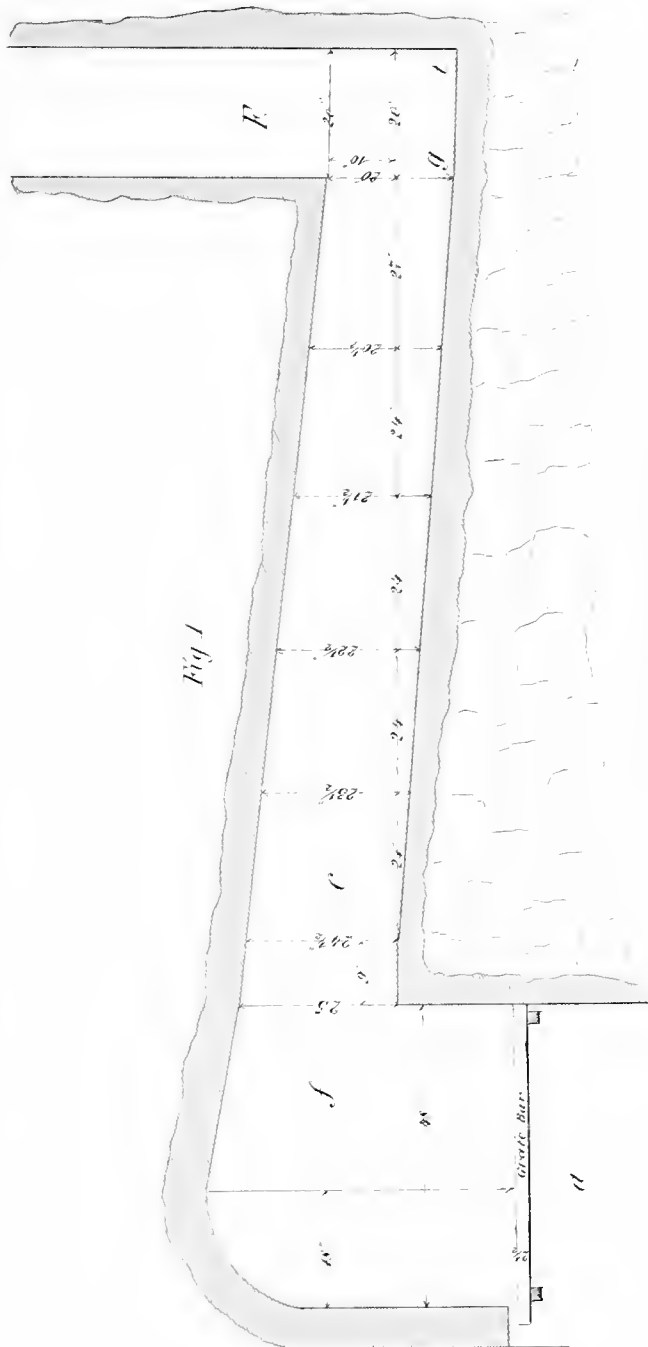
MELTED IN THE SAME FURNACES, BUT

DIFFERENTLY COOLED.

PLATE I.

West Point Furnace.

Fig. 1

Fig. 2

PLATE II

Fort Pitt Furnace

5 Feet
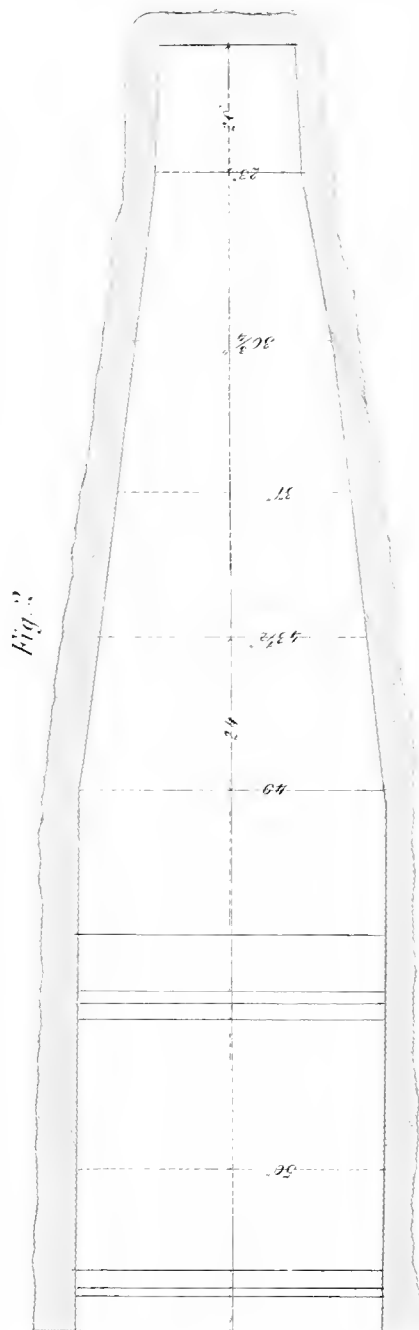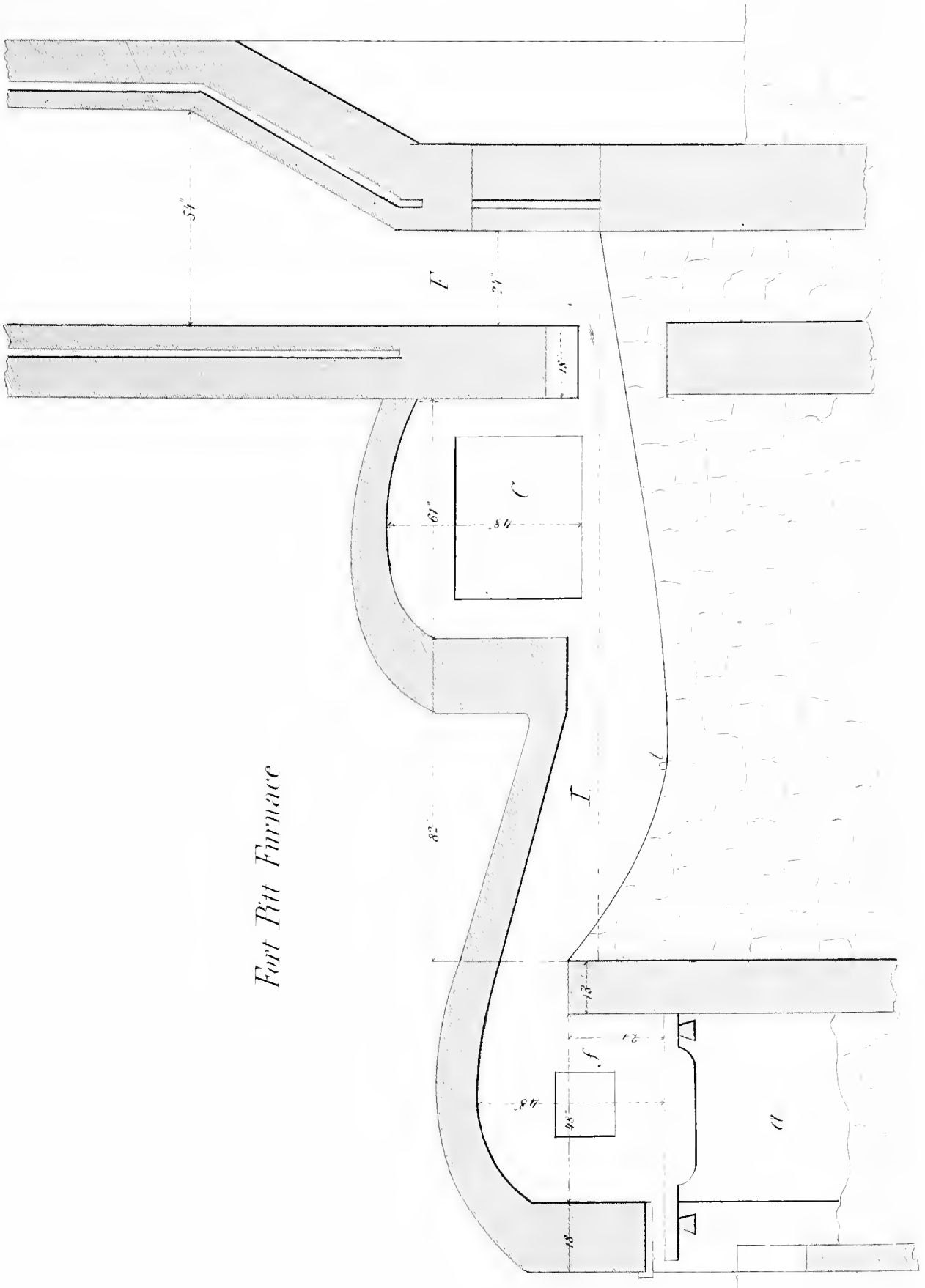
REPORT

EXPERIMENTS MADE FOR THE PURPOSE OF DETERMINING THE RELA-
TIVE ENDURANCE OF GUNS MADE FROM THE SAME IRON, BUT
MELTED IN FURNACES OF DIFFERENT CONSTRUCTION; ALSO, THAT
OF THOSE MADE FROM THE SAME IRON, MELTED IN THE SAME
FURNACES, BUT DIFFERENTLY COOLED; ONE GUN BEING CAST
SOLID, AND COOLED FROM THE EXTERIOR, AND THE OTHER CAST
HOLLOW, AND COOLED FROM THE INTERIOR.

AT the West Point Foundry, on the 2d and 3d of July, 1857, being assisted
by Lieut. F. I. Shunk, I selected a sufficient quantity of iron for the fabrica-
tion of 6 10-inch Columbiads. The iron selected was in the following
proportions, viz. : — Of *Greenwood iron*, 405 cwt. of No. 1, 500 cwt. of
No. 2, and 205 cwt. of No. 3. Of *Salisbury iron*, 225 cwt. Of *Scotch pig*,
45 cwt. Of *re-melted iron*, in the above proportions, 115 cwt.

Of this iron, two-thirds, or enough for 4 10-inch guns, was distinctly marked
on every pig, and sent to the Fort Pitt Foundry, each kind having a separate
mark. The other third was left at the West Point Foundry, each kind being
put in a separate pile.

In order to insure identity in the quality of the iron to be used at the
different furnaces, it was selected in the following manner, viz. :—

It was first classified at the smelting furnace, into the grades Nos. 1, 2, and
3, pig; after which, the different grades of Greenwood iron were kept
separate, loaded into wagons, hauled to the river, unloaded, re-loaded on a
boat, landed at the foundry wharf, loaded on cars, hauled to the foundry
yard, there unloaded, and piled in separate piles.

From the piles thus made were taken, alternately, two pigs to go to Fort
Pitt, and one to remain.

The same mode was pursued in selecting the Salisbury, Scotch, and re-melted iron.

That sent to the Fort Pitt Foundry was assorted under my own supervision, for charging the furnaces; the marks which I had seen put on being perfectly distinct on every pig.

Lieut. Shunk supervised the charging of the West Point furnaces, from the iron which he had assisted me to select.

The iron was used at both foundries in the same proportions as those in which it had been selected; and it was intended that on the same day on which the West Point Foundry would cast one solid 10-inch gun, the Fort Pitt Foundry would cast two, one solid and the other hollow; but, owing to mismanagement in the Post Office Department, my letter of the 8th of August, advising the proprietors of the West Point Foundry that we would cast on the 13th of that month, was not received till the morning of the latter date, and the West Point gun was not cast till the following day.

The quantities of iron used in charging the West Point furnace, as furnished by Lieut. Shunk, are as follows, viz. : —

Greenwood iron, No. 1 pig, ...	5936 lbs.
" " " 2 "	7504 "
" " " 3 "	3136 "
Salisbury iron, pig, ...	3360 "
Scotch iron, pig, ...	672 "
Re-melted iron, ...	2240 "
Total charge, ...	22848 lbs.

This iron was charged in three furnaces; the quantity charged in each furnace is not given.

The iron at the Fort Pitt Foundry was as follows, viz. : —

Greenwood iron, No. 1 pig, . . .	13500 lbs.
" " " 2 "	16500 "
" " " 3 "	6833 "
Salisbury iron, pig, ...	7500 "
Scotch iron, pig, ...	1500 "
Re-melted iron, ...	3833 "
Total charge, ...	49766 lbs.

This iron was charged in three furnaces, the different kinds of iron being in the same proportion in each.

Furnace No. 1 received, ... 12983 lbs.
"   " 2 "   . . . . 16848 "
"   " 3 "   . . . . 19935 "

Total, as above, ... 49766 lbs.

Of the Flasks.

The flasks in which these guns were cast were all of circular cross section; and of sufficient size to admit a wall of sand around the gun, of from 4 to 5 inches thick.

The flask in which the West Point gun was cast, was placed in an open pit, and rammed up all round with moulding sand, to a point a little above the position of the trunnions, green or moist sand being used for this purpose.

Those in which the Fort Pitt guns were cast, were placed in pits with closely fitting covers, but not rammed up with sand.

Of the Pits.

The pits in which the Fort Pitt guns were cast, were both heated by fire previous to casting. That in which the solid gun was cast, had fire lighted in it on the 10th of August, which continued to burn till the gun was cast, at which time it was burning moderately, and was allowed to burn out, no fuel being added to it after casting.

This pit was in good order for slow and regular cooling.

That in which the hollow gun was cast had a brisk fire lighted in it on the evening of the 8th of August, which continued to burn till the 11th; and on the 12th the ashes were cleaned out, and fresh fuel placed on the grate bars. This fuel ignited from drops of melted iron, which fell upon it while casting, and soon produced a brisk fire, which was kept burning till 1 o'clock, P. M., on the 15th, after which time no more fuel was added.

Of the Furnaces.

The furnaces in which the iron for all these guns was melted, are what are termed *air furnaces.*

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In these furnaces the draft is produced by chimneys, instead of a blast, which is used in the cupola furnace. The metal for what is termed a "heat," is all placed in the metal chamber before the furnace is lighted.

The fuel is placed on grate bars in the fuel chamber, or fire-place, and the flame from this fuel passes through the metal chamber on its way to the chimney. The iron is melted by this flame, without coming in contact with solid carbon at all, which is not the case in the cupola furnace, where the fuel and iron are mixed together.

The main feature of difference between the Fort Pitt and West Point furnaces is, that in the Fort Pitt furnaces, the iron, as it melts, runs back towards the bridge wall, the crown of the furnace over the bridge wall being so constructed as to cause the flame to impinge against the surface of the pool of melted metal, while at its greatest temperature; whereas, in the West Point furnace, the melted iron flows from the bridge wall, or along with the flame, so that the flame does not reach the deepest part of the metal pool till after its temperature has been somewhat reduced, and does not at any time impinge so directly against the surface of the melted iron, as in the Fort Pitt furnaces.

Figure 1, Plate 1, shows a vertical section; and Figure 2, same plate, shows the plan of the West Point furnaces. Plate 2, shows a vertical section of the Fort Pitt furnaces.

The same letter corresponds to like parts in each (*a*) ash pit (*f*), fuel chamber (*c*), metal chamber (*F*), chimney flues (*g*), metal pool, and (*t*) tap-hole.

These drawings are only intended to give a general idea of the construction of these furnaces, not being accurately drawn to any particular scale.

Casting.

The furnaces from which the Fort Pitt guns were cast, were all lighted at 9 A. M., on the 13th of August, and the metal was melted at 12½ P. M. Furnace No. 3 was tapped at 2h. 5m. P. M., and No. 2 two minutes after; No. 1 not being tapped till after the metal from No. 3 had ceased to flow; so that the metal flowed from only two furnaces at the same time.

The metal appeared fluid, and in good order for casting, and was all received into one vessel, from which it issued at two orifices, and ran in separate runners to the two gun moulds, which it entered simultaneously by side

runners, one to each mould, till the metal had risen above the trunnions, when the side runners were closed, and the metal entered the moulds directly at their mouths.

The hollow gun mould was filled in 8 minutes, and the solid one in $9\frac{1}{2}$ minutes after the first metal entered.

Lieut. Shunk writes in relation to casting the West Point gun, as follows, viz. :—

"The iron was taken from the piles you specified; set fire at 8 A. M., down at $1\frac{1}{2}$ P. M., cast at 4 P. M. — Time in fusion, $2\frac{1}{2}$ hours. The metal appeared as usual, and entered both sides of the mould. The proof bars were failures, from a mixture of slag."

Cooling.

The West Point gun, No. 983, cooled in the mould, rammed up in green sand, as before described, from which it was removed on the 8th day after casting.

Water circulated through the core barrel of the hollow cast gun (No. 334), from the time the metal reached the bottom of the core in casting, till the core barrel was removed, at the rate of three cubic feet per minute.

Just after casting, the water entered at 75°, and left at 95°. At 16 hours after casting, the core barrel was removed, and the water circulated through the cavity thus left, at the rate of two cubic feet per minute. Just after the removal of the core barrel, the water entered at 75°, and left at 136°.

At $19\frac{1}{2}$ hours after casting, the flow of water was increased to three cubic feet per minute; at which time and rate it entered at 75°, and left at 108°.

Water continued to circulate through the gun at rates varying but little from three cubic feet per minute, and leaving with a gradually decreasing temperature, till $11\frac{1}{2}$ A. M., on the 21st, at which time it entered and left at the same temperature.

The water was then shut off, and the pit uncovered for the removal of the flask from the gun.

The gun was hoisted out of the pit at 6 P. M.; and water which had remained in the gun from $11\frac{1}{2}$ A. M. of same day, till that time, had a temperature of 80°.

The solid cast gun, No. 335, remained in the pit, as before described, till the afternoon of the 25th, when it was removed from flask and pit.

Both these guns were cast considerably larger than the finished gun, from a short distance in front of the chase curves to the tops of the sinking heads, which were about 2½ feet long in both guns.

There was a marked difference in the appearance of the newly-turned surfaces of these guns; the solid cast gun presented a clouded or dappled appearance, while the hollow one presented a much finer, and more uniformly mottled appearance.

The finished hollow cast gun was marked on one side, just at the neck-ring, with small cavities, some of them to the depth of perhaps three-tenths of an inch.

These I was at first disposed to attribute to what is called soakage; but, from the fact that they made their appearance near the exterior surface of the casting, I am rather inclined to regard them as sand holes, caused by small particles of sand or scoria lodging in that part of the casting.

The guns were all accurately measured, and found to be within the prescribed limits of variation, except that the West Point gun was 25 inches greater than the prescribed diameter at the swell of the muzzle, and 15 inches less in total length of bore.

The West Point gun was received here on the 20th of October; and, together with the Fort Pitt guns, had the proof charges fired from it on the 22d of that month.

The guns were then suspended for extreme proof, each in its own frame.

Proof Charges.

First fire, 20 lbs. powder, one strapped shot, and one wad, above the shot. 2d fire, 24 lbs. powder, and one strapped shell.

Service Charges.

14 lbs. powder, and one solid shot, strapped; the charges of powder were all weighed.

Of the Powder.

All the powder used in the proof of these guns was made by the Messrs. Dupont, in 1857. It was highly glazed, remarkably free from dust, and very uniform in size of grain.

Mean eprouvette range, from 295 to 300 yards.

Ranges of the proof charges were 311 for the shot, and 312 for the shells.

In order to insure equality in the proof of the different guns, they were fired alternate rounds, with charges of powder of the same eprouvette range, and taken from the same cask.

Six cartridges were taken from each of three bands, and what remained in them all was put into one, and well rolled and shaken up, and from this three other cartridges were made; this mode gave even rounds for the three guns; and the same principle was observed in the preparation of the cartridges for the two that remained after the first one broke.

The cartridges all had their proof ranges marked on them in the laboratory, and were finished on blocks 7.25 inch diameter, and of sufficient thickness to make the finished cartridge 12 inches long, or to fill the chamber.

Of the three shells used in the proof, and afterwards recovered, one was apparently uninjured; one was found in fragments in the bank into which it had been fired, and the other was considerably distorted, and slightly cracked in the fuze hole.

Mode of Discharging the Guns.

These guns were all fired with friction tubes; those used in the first part of the firing were made at Fort Monroe Arsenal, had been on hand for some time, and frequently failed. The latter part of the firing was done with tubes made at the Frankford Arsenal, of which not over two per cent. failed.

Endurance of the Guns.

These guns all enlarged more than usual under the proof charges; but no other indications of rupture were observed, till after the 88th fire, when both the solid cast guns were observed to be cracked at the junction of the chamber and taper.

Two cracks, on nearly opposite sides, were observable in the Fort Pitt gun, and but one in the West Point gun; those in the Fort Pitt gun appeared to be largest.

These cracks all gradually increased with subsequent firing; those in the Fort Pitt gun appeared to open more, while that in the West Point gun

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extended longitudinally, and was soon accompanied by another, about 100° distant from it.

The West Point gun broke through the above described cracks, at the 169th fire, including the proof charges; this gun broke into three pieces, splitting through the breech, and forward, just to include the left trunnion in the largest of the two small pieces, leaving one-fourth of breech and cylinder, and the other trunnion attached to the chase. The only peculiarities in the fracture of this gun are, that it had three longitudinal lines of fracture, which I have never before known to occur in guns of this calibre; and the unusually short distance from the breech to which the fracture extended.

The crack in the Fort Pitt solid cast gun continued to open and extend further into the chamber, other cracks making their appearance as the firing proceeded; till, at the last observation, the two first described cracks extended from the junction of the bore and taper, down into the hemisphere of the chamber, leaving about 2 inches of apparently solid metal between them.

This gun broke at the 399th fire, into three pieces, through the first named cracks, the cylinder breaking into two nearly equal pieces through the breech.

The fracture extended forward above the left, and below the right trunnions, to a short distance in front of the trunnions, where the two breech pieces broke off from the chase.

In the bottom of the bore, and a short distance in front of the seat of shot in this gun, were two or three small cavities, indicative of "soakage."

No cracks were observed in the hollow cast gun till after about the 600th fire, when a number of small cracks were observed just at the junction of the chamber and taper; these cracks had not the tortuous appearance of those in the other guns, but had more the appearance of having been cut and burned out by the gas.

Cracks of this character continued to multiply as the firing progressed; but none of them appeared to enlarge perceptibly from day to day, as those in the other guns, till about the 1000th round, when the whole chamber and taper were marked by an almost infinite number of small, shallow cracks, the bottom of the chamber having a net-like appearance; and three cracks, larger than the rest, appeared to be extending down into the chamber.

These cracks continued to extend very slowly with subsequent firing, and had, at the 1600th fire, extended three or four inches into the chamber, and

about the same distance into the taper; the interior appearance of the gun having in no other wise changed.

This gun has been fired 1600 rounds, including proof charges; two new vents were inserted, one after the 529th fire, and the other after the 1040th fire. The vents in all these guns were bored in planes perpendicular to the axis of the guns, at the junction of the hemispheres and cylinders of the chambers; and 6 inches on the exterior, and 3 inches on the interior, from a plane through the axis of the gun, and perpendicular to that of the trunnions.

Plate 3 shows the lines of fracture in the Fort Pitt gun, and Plate 4 shows those of the West Point gun. Plate 5 shows the positions of the different specimens for density and tenacity in the guns from which they were taken; specimens from corresponding positions being similarly marked and numbered.

Head specimens were taken (c) from the axis (1), from near surface of bore (2), from middle of thickness, and (3) from near exterior surface; axis of all, parallel to those of the guns from which they were taken.

TABLE *showing the interior measurement of the first set of triplicate Columbiads, of* 1857.

Distance from Muzzle.	Hollow. No. 334.		F. P. F. Solid. No. 335.		W. P. F. Solid. No. 983.	
	Before Proof.	After Proof.	Before Proof.	After Proof.	Before Proof.	After Proof.
10	10.004	10.004	10.002	10.004	10.001	10.002
20	5	5	3	3	1	2
30	6	6	4	5	1	2
40	7	7	5	6	1	2
50	8	8	5	6	0	2
60	8	8	5	5	0	2
70	7	7	4	4	1	2
80	6	6	4	13	0	5
81	5	5	4	10	0	5
82	5	5	4	7	0	3
83	6	6	4	7	0	3
84	5	6	4	7	0	3
85	5	5	4	7	0	3
86	5	5	4	8	0	3
87	6	6	4	8	0	3
88	6	7	4	9	0	3
89	6	9	5	24	0	11
90	6	27	5	57	0	35
91	6	47	5	80	0	52
92	6	55	5	83	0	47
$92\frac{1}{2}$	7	54	4	82	1	22
$99\frac{1}{2}$	8.013	8.015	8.011	8.018	8.022	8.023
103	8.010	.010	9	13	12	22
$106\frac{1}{2}$	8.010	.010	9.	10	0	3

This, and following tables of enlargements, are recorded as read from the Star Gauge, which accounts for apparent discrepancies.

PLATE III.

Side elevation

Top View

End View

B

C

Scale ⅕ᵗʰ Size
Gun Nº 335
F.P.F.

PLATE IV
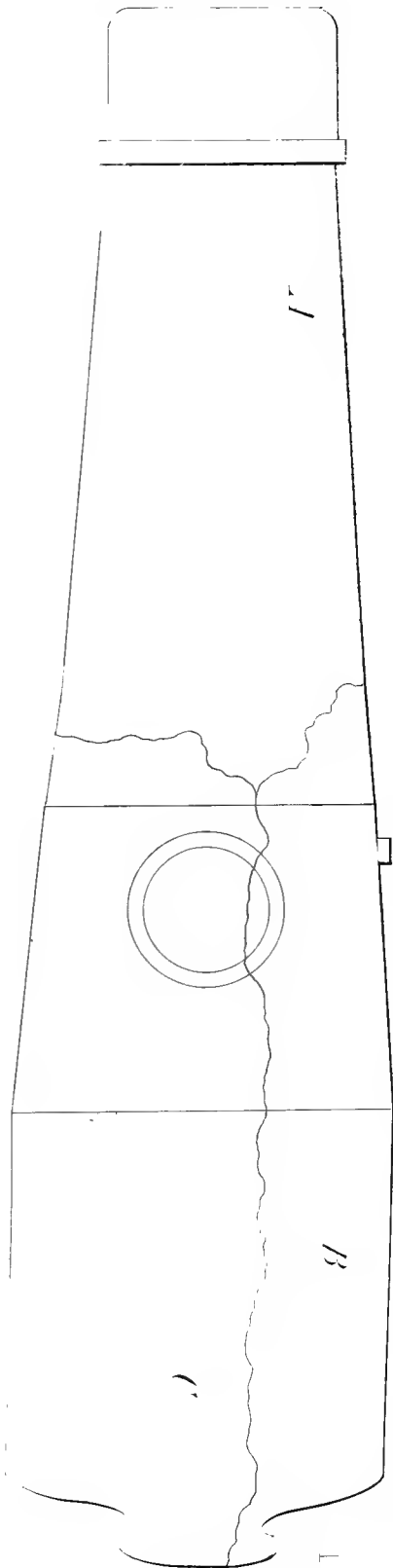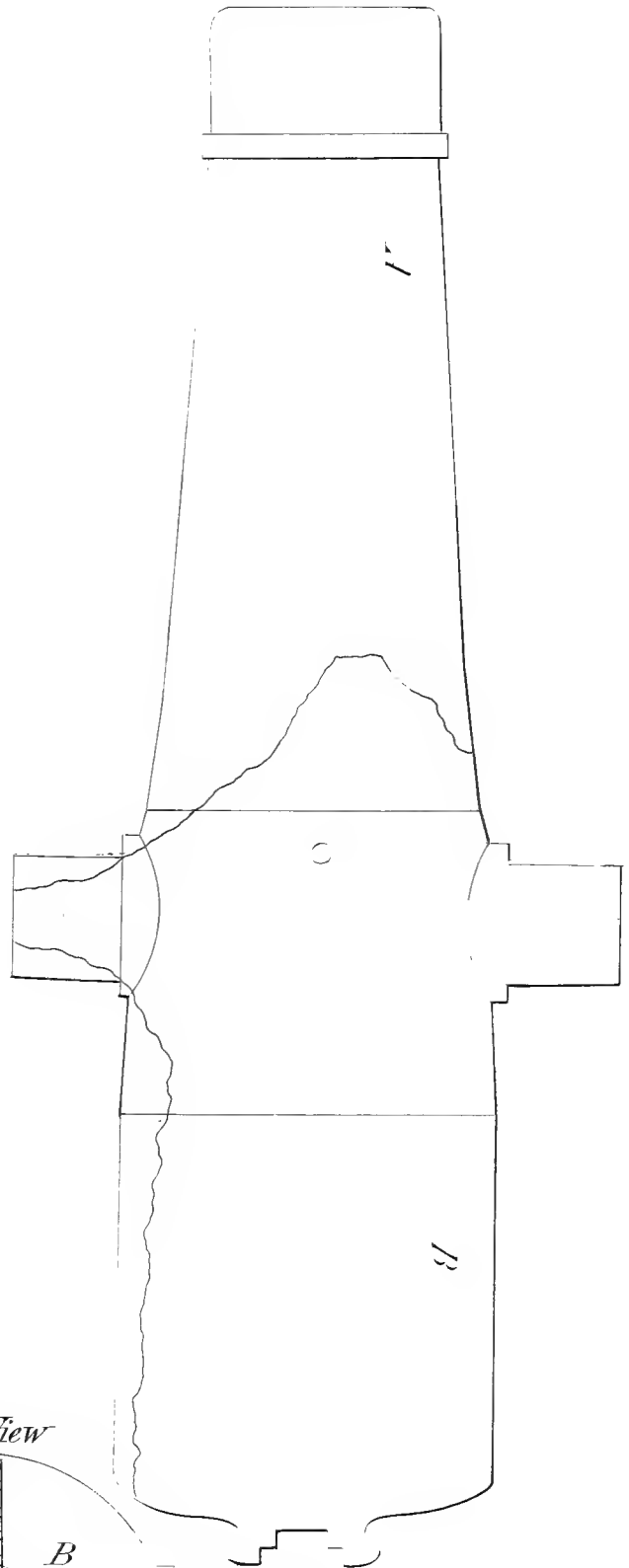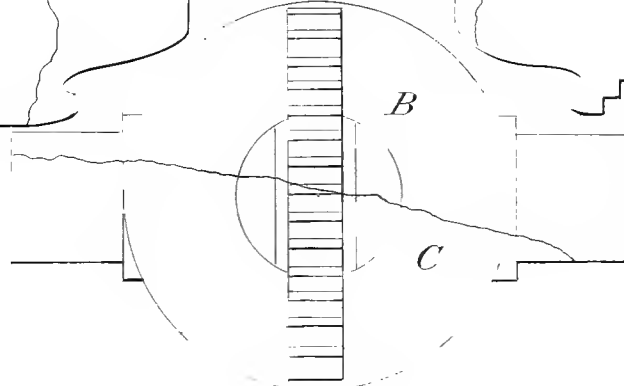
Side elevation

Top View

End View

Scale ⅕th Size
Gun Nº 983.
W. P. F.

PLATE V
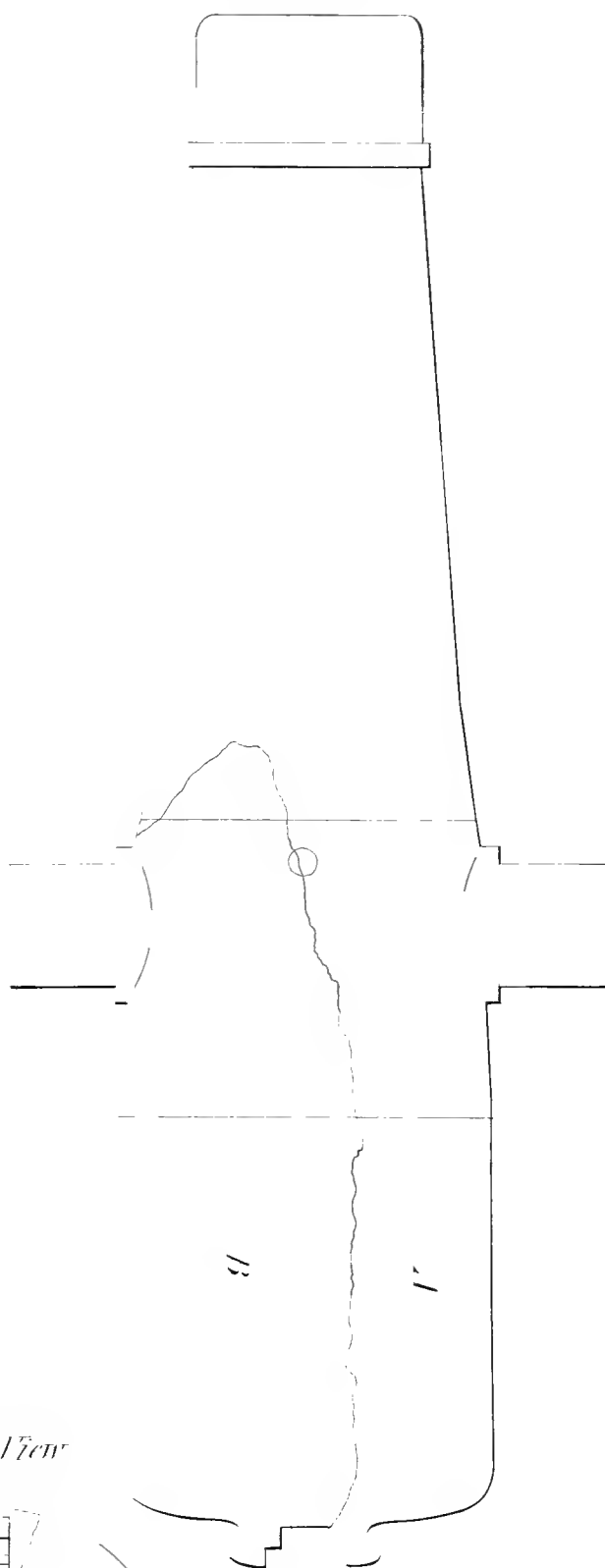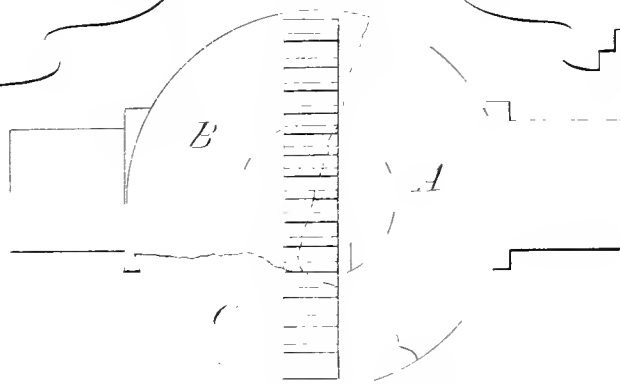
Drawing showing Position
of Specimens for Density and
Tensile Strength.
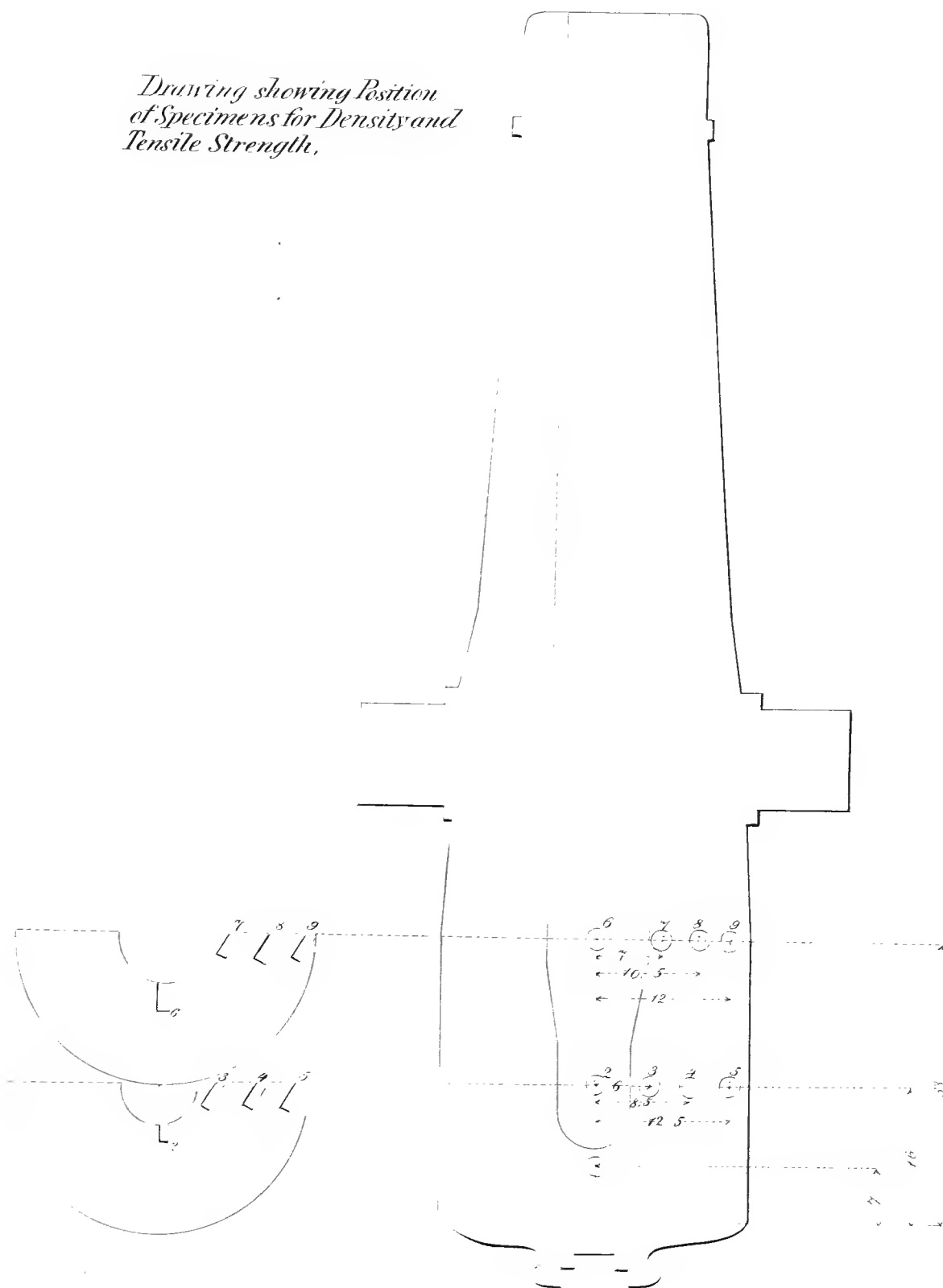
TABLE *showing enlargement of bores and chambers above their original diameters, after the undermentioned numbers of fires, in thousandths of an inch.*

Distance from Muzzle.	2D FIRE. (Proof.)			14TH FIRE.			28TH FIRE.			48TH FIRE.		
	Fort Pitt.		W. P.	Fort Pitt.		W. P.	Fort Pitt.		W. P.	Fort Pitt.		W. P.
	Hollow. 334	Solid. 335	Solid. 983	Hollow. 334	Solid. 335	Solid. 983	Hollow. 334	Solid. 335	Solid. 983	Hollow. 334	Solid. 335	Solid. 983
10	0	2	0	0	2	0	0	2	0	0	2	0
20	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	2	1	0	2	1	0	2	2	0
40	0	1	0	1	1	0	1	1	0	1	2	0
50	0	1	1	0	2	1	0	2	1	0	3	1
60	0	4	1	0	5	1	0	5	1	0	6	1
70	0	0	0	0	1	0	0	2	0	0	3	0
80	0	9	3	0	10	3	0	11	3	0	11	3
81	0	7	4	0	8	4	0	9	4	0	10	4
82	0	4	1	0	5	1	0	5	1	0	6	1
83	0	3	1	0	3	1	0	3	1	0	3	1
84	0	3	3	0	3	3	0	3	3	0	3	3
85	0	3	3	0	3	3	0	3	4	0	3	4
86	0	3	3	1	3	3	1	3	4	1	3	4
87	0	4	3	0	4	3	0	4	4	0	4	4
88	1	5	3	1	6	4	1	7	4	1	8	4
89	3	19	8	14	26	8	14	30	9	14	34	10
90	21	52	27	25	61	28	25	65	28	25	68	29
91	36	75	41	36	90	41	36	93	42	36	95	44
92	49	78	42	50	95	42	50	97	42	50	98	42
92½	47	78	22	53	87	22	53	92	22	53	94	22

CHAMBERS.

99½	2	7	1	5	13	3	5	10	4	5	16	5
103	0	4	0	2	8	2	2	8	3	2	10	4
106½	0	1	0	1	6	0	1	7	0	1	8	1

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Enlargement of Bores and Chambers—Continued.

Distance from Muzzle	68TH FIRE.						88TH FIRE.					
	Fort Pitt.				W. P.		Fort Pitt.				W. P.	
	Hollow. No. 334.		Solid. No. 335.		Solid. No. 983.		Hollow. No. 334.		Solid. No. 335.		Solid. No. 983.	
	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.
10	—	0	—	2	—	0	—	0	—	3	—	0
20	—	0	—	1	—	0	—	0	—	1	—	0
30	—	21	—	3	—	0	—	2	—	3	—	0
40	—	0	—	2	—	0	—	1	—	2	—	0
50	—	0	—	4	—	1	—	0	—	4	—	1
60	—	0	—	6	—	1	—	0	—	6	—	1
70	—	0	—	3	—	0	—	0	—	4	—	0
80	—	0	—	12	—	3	—	0	—	12	—	4
81	—	0	—	10	—	4	—	0	—	11	—	4
82	—	0	—	6	—	1	—	0	—	6	—	1
83	—	0	—	4	—	1	—	0	—	4	—	1
84	—	0	—	3	—	3	—	0	—	4	—	3
85	—	0	—	3	—	4	—	0	—	4	—	4
86	—	1	—	3	—	4	—	1	—	3	—	4
87	—	0	—	4	—	4	—	0	—	4	—	4
88	1	1	8	9	5	5	1	1	8	10	5	5
89	3	14	9	36	8	12	3	14	9	38	8	12
90	4	25	13	70	9	30	4	25	13	71	9	31
91	5	36	20	96	9	46	5	36	20	96	9	48
92	17	50	25	98	10	43	17	50	26	98	10	44
92½	21	53	28	95	1	22	22	30	30	96	1	24

CHAMBERS.

99½	5	5	14	16	6	6	5	5	15	16	7	6
103	1	2	9	10	6	5	1	2	9	11	6	5
106½	0	1	8	9	5	2	0	1	8	9	6	3

Enlargement of Bores and Chambers—Continued.

Distance from Muzzle.	108TH FIRE.						133D FIRE.					
	Fort Pitt.				W. P.		Fort Pitt.				W. P.	
	Hollow. 334.		Solid. 335.		Solid. 983.		Hollow. 334.		Solid. 335.		Solid. 983.	
	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.
10	—	0	—	3	—	0	—	0	—	3	—	0
20	—	0	—	2	—	0	—	0	—	2	—	0
30	—	2	—	3	—	0	—	2	—	3	—	0
40	—	1	—	3	—	0	—	1	—	3	—	0
50	—	0	—	4	—	1	—	0	—	5	—	1
60	—	0	—	6	—	2	—	0	—	7	—	2
70	—	0	—	4	—	0	—	0	—	4	—	1
80	—	0	—	12	—	4	—	0·	—	13	—	4
81	—	0	—	11	—	4	—	0	—	12	—	5
82	—	0	—	6	—	1	—	0	—	7	—	2
83	—	0	—	4	—	1	—	0	—	4	—	2
84	—	0	—	4	—	3	—	0	—	4	—	3
85	—	0	—	4	—	4	—	0	—	5	—	5
86	—	1	—	4	—	4	—	1	—	4	—	5
87	—	0	—	4	—	4	—	0	—	4	—	5
88	1	2	8	12	5	5	1	2	8	14	6	6
89	3	14	9	40	8	13	3	15	9	41	8	14
90	4	25	14	72	9	33	4	25	14	73	9	34
91	5	36	20	97	9	50	5	36	20	97	9	52
92	17	50	27	99	10	46	18	50	28	99	10	49
92½	23	53	32	98	1	25	24	53	33	100	1	27

CHAMBERS.

99½	5	5	15	17	7	7	5	5	16	17	7	7
103	1	2	9	12	6	6	1	2	9	13	6	7
106½	0	1	8	9	0	0	0	1	8	9	0	0

Enlargement of Bores and Chambers—Continued.

Distance from Muzzle.	158TH FIRE.						190TH FIRE.				210TH FIRE.			
	Fort Pitt.				W. P.		Fort Pitt.				Fort Pitt.			
	Hollow. 334.		Solid. 335.		Solid. 983.		Hollow. 334.		Solid. 335.		Hollow. 334.		Solid. 335.	
	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.
10	–	0	–	3	–	0	–	0	–	4	–	0	–	4
20	–	0	–	2	–	0	–	0	–	3	–	0	–	3
30	–	2	–	4	–	0	–	2	–	4	–	2	–	4
40	–	1	–	4	–	0	–	1	–	4	–	1	–	4
50	–	0	–	5	–	1	–	0	–	6	–	0	–	6
60	–	0	–	7	–	2	–	0	–	8	–	0	–	8
70	–	0	–	5	–	1	–	0	–	5	–	0	–	5
80	–	0	–	13	–	5	–	0	–	13	–	0	–	14
81	–	0	–	12	–	6	–	0	–	13	–	0	–	13
82	–	0	–	7	–	2	–	0	–	8	–	0	–	8
83	–	0	–	5	–	2	–	0	–	5	–	0	–	6
84	–	0	–	5	–	4	–	0	–	5	–	0	–	5
85	–	0	–	5	–	5	–	0	–	5	–	0	–	6
86	–	1	–	4	–	5	–	1	–	5	–	1	–	5
87	–	0	–	4	–	5	–	0	–	5	–	0	–	5
88	1	3	8	15	6	6	1	3	9	16	1	3	9	16
89	3	15	9	43	8	15	3	15	10	45	3	15	10	47
90	4	25	15	74	9	35	4	25	15	75	4	25	15	76
91	5	36	20	97	9	54	5	36	21	98	6	36	21	98
92	18	50	28	100	10	50	19	50	29	101	20	51	29	102
92½	24	53	35	101	1	30	26	53	35	103	28	54	36	107

CHAMBERS.

99½	5	5	17	18	7	8	5	5	18	18	5	6	18	19
103	1	2	9	14	6	8	1	2	10	15	1	2	10	15
106½	0	1	8	10	0	0	0	1	8	10	0	1	8	10

Enlargement of Bores and Chambers—Continued.

Distance from Muzzle.	241ST FIRE.				272D FIRE.				304TH FIRE.			
	Fort Pitt.				Fort Pitt.				Fort Pitt.			
	Hollow. 334.		Solid. 335.		Hollow. 334.		Solid. 335.		Hollow. 334.		Solid. 335.	
	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.
10	—	0	—	5	—	0	—	6	—	1	—	7
20	—	0	—	4	—	0	—	5	—	0	—	5
30	—	2	—	5	—	2	—	5	—	2	—	5
40	—	1	—	5	—	1	—	5	—	1	—	6
50	—	0	—	7	—	0	—	7	—	0	—	8
60	—	0	—	8	—	0	—	9	—	0	—	9
70	—	0	—	6	—	0	—	6	—	0	—	7
80	—	0	—	14	—	0	—	14	—	0	—	15
81	—	0	—	13	—	0	—	14	—	0	—	14
82	—	0	—	9	—	0	—	9	—	0	—	9
83	—	0	—	6	—	0	—	7	—	0	—	7
84	—	0	—	6	—	0	—	6	—	0	—	7
85	—	0	—	6	—	0	—	7	—	1	—	7
86	—	1	—	6	—	1	—	6	—	1	—	6
87	—	0	—	6	—	1	—	6	—	1	—	7
88	2	4	9	17	3	4	10	19	3	4	10	21
89	3	15	11	49	3	15	12	51	3	15	13	53
90	5	25	16	77	6	25	17	78	7	25	17	79
91	6	36	21	99	7	37	22	100	7	37	22	102
92	21	52	30	106	23	52	32	109	24	53	34	114
92½	30	55	37	112	33	56	37	116	35	56	38	118

CHAMBERS.

99½	5	6	18	20	6	7	19	21	6	7	19	22
103	1	2	11	16	1	2	11	17	1	3	11	19
106½	0	1	8	12	0	1	9	13	0	1	9	14

Enlargement of Bores and Chambers—Continued.

Distance from Muzzle.	336TH FIRE. Fort Pitt.				368TH FIRE. Fort Pitt.				401ST FIRE. Fort Pitt.		457TH FIRE. Fort Pitt.	
	Hollow. 334.		Solid. 335.		Hollow. 334.		Solid. 335.		Hollow. 334.		Hollow. 334.	
	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.
10	—	1	—	8	—	1	—	8	—	2	—	2
20	—	0	—	6	—	0	—	7	—	0	—	1
30	—	2	—	6	—	2	—	6	—	2	—	2
40	—	1	—	7	—	1	—	8	—	2	—	2
50	—	0	—	9	—	0	—	9	—	0	—	1
60	—	0	—	10	—	0	—	10	—	0	—	0
70	—	1	—	8	—	1	—	9	—	1	—	2
80	—	0	—	15	—	0	—	15	—	0	—	1
81	—	0	—	14	—	0	—	14	—	0	—	0
82	—	0	—	10	—	0	—	10	—	0	—	1
83	—	0	—	8	—	0	—	8	—	0	—	0
84	—	0	—	8	—	0	—	9	—	0	—	1
85	—	1	—	8	—	1	—	9	—	2	—	2
86	—	1	—	6	—	1	—	7	—	2	—	2
87	—	1	—	7	—	1	—	8	—	1	—	2
88	4	5	10	23	4	5	10	27	5	6	5	6
89	4	15	14	56	4	16	15	61	4	16	5	17
90	7	25	18	81	8	26	18	83	8	26	8	26
91	7	38	23	105	7	38	23	112	8	40	8	43
92	25	54	37	118	26	56	41	119	27	59	29	66
92½	37	57	41	120	40	60	43	123	42	64	45	69

CHAMBERS.

99½	6	8	20	24	6	9	22	29	6	10	6	10
103	1	3	11	20	1	3	11	23	2	3	3	4
106½	0	1	9	15	0	1	10	17	0	1	0	1

Enlargement of Bores and Chambers—Continued.

Distance from Muzzle.	529TH FIRE.		590TH FIRE.		665TH FIRE.		793RD FIRE.		804TH FIRE.	
	Fort Pitt.		Fort Pitt.		Fort Pitt.		Fort Pitt.		Fort Pitt.	
	Hollow. 334.		Hollow. 334.		Hollow. 334.		Hollow. 334.		Hollow. 334.	
	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.
1,0	—	2	—	2	—	3	—	3	—	4
20	—	1	—	1	—	2	—	2	—	3
30	—	2	—	2	—	2	—	2	—	3
40	—	2	—	3	—	4	—	4	—	4
50	—	1	—	2	—	4	—	4	—	4
60	—	0	—	1	—	1	—	1	—	2
70	—	2	—	3	—	3	—	3	—	3
80	—	1	—	1	—	2	—	2	—	2
81	—	1	—	1	—	1	—	1	—	1
82	—	1	—	1	—	1	—	1	—	1
83	—	1	—	1	—	1	—	1	—	1
84	—	2	—	2	—	2	—	2	—	2
85	—	3	—	3	—	3	—	3	—	3
86	—	3	—	3	—	3	—	3	—	4
87	—	3	—	3	—	3	—	3	—	4
88	6	5	6	6	7	6	7	6	7	6
89	5	17	6	18	6	19	7	20	7	21
90	8	27	8	28	9	30	9	33	10	35
91	8	46	9	50	10	54	11	58	13	63
92	33	74	37	82	43	90	48	96	53	102
$92\frac{1}{2}$	49	76	54	83	60	89	66	94	71	79

CHAMBERS.

$99\frac{1}{2}$	6	11	6	11	6	13	7 ·	15	7	16
103	3	4	4	4	4	4	5	5	5	6
$106\frac{1}{2}$	0	1	1	1	1	1	1	1	1	1

Enlargement of Bores and Chambers—Continued.

Distance from Muzzle.	885TH FIRE. Fort Pitt. Hollow. 334.		961ST FIRE. Fort Pitt. Hollow 334.		1040TH FIRE. Fort Pitt. Hollow. 334.		1120TH FIRE. Fort Pitt. Hollow. 334.		1200TH FIRE. Fort Pitt. Hollow. 334.	
	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.
10	—	5	—	5	—	6	—	6	—	. 6
20	—	4	—	5	—	5	—	6	—	6
30	—	4	—	5	—	5	—	6	—	7
40	—	4	—	5	—	5	—	6	—	6
50	—	4	—	5	—	6	—	6	—	7
60	—	2	—	3	—	3	—	4	—	4
70	—	3	—	4	—	4	—	5	—	6
80	—	2	—	3	—	3	—	3	—	4
81	—	2	—	2	—	2	—	3	—	3
82	—	1	—	2	—	3	—	3	—	3
83	—	1	—	2	—	2	—	3	—	3
84	—	3	—	3	—	4	—	4	—	4
85	—	4	—	4	—	5	—	6	—	7
86	—	4	—	4	—	5	—	5	—	6
87	—	4	—	4	—	5	—	5	—	6
88	6	8	7	9	7	10	8	10	8	11
89	8	22	8	23	9	24	10	25	11	26
90	12	36	14	37	14	38	15	39	16	40
91	16	69	20	75	25	77	28	80	32	84
92	57	105	63	108	68	111	74	114	80	117
92½	75	105	81	109	85	113	92	116	98	118

CHAMBERS.

99½	7	17	8	19	8	20	8	23	8	26
103	6	7	6	8	6	8	6	9	6	11
106½	1	2	1	2	1	2	2	3	2	4

Enlargement of Bores and Chambers—Continued.

Distance from Muzzle.	1280TH FIRE. Fort Pitt. Hollow. 334.		1360TH FIRE. Fort Pitt. Hollow. 334.		1440TH FIRE. Fort Pitt. Hollow. 334.		1520th FIRE. Fort Pitt. Hollow. 334.		1600TH FIRE. Fort Pitt. Hollow. 334.	
	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.	Horz.	Vert.
10	—	7	—	8	—	9	—	10	11	12
20	—	6	—	7	—	8	—	9	10	9
30	—	8	—	9	—	10	—	11	11	12
40	—	7	—	8	—	9	—	9	9	10
50	—	8	—	8	—	9	—	10	7	10
60	—	5	—	6	—	7	—	7	7	8
70	—	7	—	8	—	9	—	10	10	11
80	—	5	—	5	—	6	—	6	7	7
81	—	4	—	4	—	5	—	5	8	6
82	—	3	—	4	—	5	—	5	6	6
83	—	3	—	4	—	4	—	5	4	5
84	—	5	—	6	—	6	—	7	5	8
85	—	7	—	8	—	9	—	10	7	10
86	—	6	—	7	—	7	—	8	9	9
87	—	6	—	7	—	7	—	8	9	9
88	9	12	9	12	10	13	11	14	11	15
89	13	27	15	28	17	29	19	30	20	30
90	17	41	19	42	21	43	22	44	24	44
91	35	88	39	90	42	92	44	94	45	95
92	85	120	90	123	96	127	101	130	105	133
92½	101	120	108	121	112	123	114	125	116	126

CHAMBERS.

99½	8	29	8	33	8	35	9	38	9	42
103	7	13	7	16	7	18	7	20	7	21
106½	2	5	3	6	4	7	4	7	4	7

20

TABLE *showing the diameters of Vents, after the undermentioned numbers of fires, in hundredths of an inch.*

Distance from Exterior.	133d Fire.			158th Fire.			190th Fire.		210th Fire.		241st Fire.	
	334	335	983	334	335	983	334	335	334	335	334	335
1	21	21	22	21	21	22	21	21	22	22	22	22
2	21	21	22	21	21	22	21	21	22	22	23	23
3	22	22	22	22	22	22	22	22	22	22	23	23
4	21	22	22	22	22	23	22	22	23	22	24	24
5	21	22	22	22	22	23	23	22	23	23	24	24
6	22	22	22	22	22	23	23	23	24	23	25	24
7	22	22	22	22	23	24	23	23	24	24	25	24
8	22	22	24	23	24	25	23	24	24	25	26	26
9	22	23	24	24	24	25	24	24	25	25	26	27
10	23	24	26	24	25	28	25	26	26	27	27	28
11	22	24	27	22	24	30	25	25	28	26	28	28

TABLE *of diameters of Vents*—Continued.

Distance from Exterior.	272d Fire.		304th Fire.		336th Fire.		368th Fire.		401st Fire.	451st Fire.	529th Fire
	334	335	334	335	334	335	334	335	334	334	334
1	22	23	24	24	24	24	25	25	26	29	31
2	24	23	24	24	25	25	26	26	27	30	31
3	24	24	25	25	25	26	26	26	28	31	33
4	24	24	25	25	26	26	27	27	30	32	35
5	25	24	26	25	27	26	29	27	30	32	36
6	26	24	26	25	28	26	30	28	31	33	35
7	27	25	27	26	30	28	31	30	32	34	35
8	27	27	27	28	30	30	33	32	33	36	38
9	27	30	28	31	30	33	33	34	34	34	40
10	28	30	29	31	30	32	34	34	34	37	42
11	29	28	30	28	33	31	34	32	38	42	42

TABLE *of diameters of Vents*—Continued.

Distance from Exterior.	809th Fire.	885th Fire.	961st Fire.	1070th Fire.	1280th Fire.	1360th Fire.	1440th Fire.	1520th Fire.	1600th Fire.
	2d vent. 334	2d vent. 334	2d vent. 334	2d vent. 334	2d vent. 334	2d vent. 334	2d vent. 334	2d vent. 334	2d vent. 334
1	23	25	27	30	32	24	25	26	30
2	24	25	26	30	22	24	26	29	30
3	23	25	28	30	22	24	25	29	32
4	24	25	27	31	22	24	27	30	33
5	24	26	30	33	23	26	28	31	35
6	25	28	31	33	24	26	28	31	35
7	26	30	32	34	24	28	32	36	40
8	26	30	33	37	25	28	32	34	37
9	27	32	36	40	26	30	33	36	42
10	26	34	38	40	27	34	35	38	46
11	30	36	39	52	30	34	36	40	65
12	—	—	30	—	29	33	37	39	70

Meteorological Observations, and Number of Rounds fired each Day.

Days of the Month	TEMPERATURE — THERMOMETER				HYGROMETER				WINDS — 7 A.M.		WINDS — 2 P.M.		WEATHER	NUMBER OF CHARGES FIRED EACH DAY		
	7 A.M.	2 P.M.	9 P.M.	Mean	7 A.M.	2 P.M.	9 P.M.	Mean	Direction	Force	Direction	Force		384	335	983
Oct. 22,	33°	51°	43°	42.33°	32°	45°	40°	39°	W.	0	E.	1	Cloudy; fog at 7 A.M.	Proof 2d. 12	Proof 2d. 12	Proof 2d. 12
" 27,	43	45	42	43.33	39	41	40	36.66	N.	4	N.	4	Cloudy; atmosphere hazy.	14	14	14
" 28,	40	45	42	42.33	38	42	40	40	S.E.	1	S.W.	1	Cloudy; atmosphere hazy.	20	20	20
" 29,	41	45	41	43	38	42	40	40	S.E.	1	W.	1	Cloudy; atmosphere hazy.	20	20	20
" 30,	40	45	38	43.33	40	44	39	40.33	E.	3	S.E.	3	Cloudy; atmosphere hazy.	20	20	20
" 31,	42	50	46	43.33	40	44	36	40	S.	2	S.E.	2	Fair.	25	25	25
Nov. 2,	46	54	35	48.66	43	44	43	43.33	S.W.	2	N.W.	7	Fair.	25	25	25
" 3,	43	50	40	42.66	38	41	37	38.33	S.W.	2	S.	7	Fair; atmosphere hazy.	32	32	11
" 4,	33	55	58	42.66	32	46	56	38.33	E.	1	S.E.	2	Showery.	25	25	—
" 5,	41	59	65	52.66	40	58	63	51.33	S.E.	1	S.	1	Showery.	32	32	—
" 6,	56	77	35	66	54	71	33	62.66	S.E.	1	W.	2	Fair.	20	20	—
" 11,	32	45	46	37	30	39	43	34	W.	1	S.W.	1	Cloudy; shower at 4 P.M.	31	31	—
" 12,	32	51	36	43	30	46	35	39.66	S.W.	0	W.	1	Cleared up at 11 A.M.	32	32	—
" 13,	43	48	29	42.33	42	44	27	40.33	S.W.	0	S.W.	2	Occasional sprinkle of snow.	32	32	—
" 14,	33	36	45	34.33	36	32	44	31.66	N.E.	2	N.	3	Occasional sprinkle of snow.	32	32	—
" 16,	33	41	40	39.66	31	40	37	38.33	S.	0	S.	1	Rain and sleet.	33	31	—
" 17,	39	42	41	40.33	38	38	39	37.66	S.W.	1	S.W.	4	Cold rain.	56	—	—
" 18,	41	45	27	42.33	39	42	35	40	S.W.	4	S.W.	8	Occasional sprinkling of rain.	8	—	—
" 19,	46	32	16	35	30	30	25	32.66	N.W.	5	N.W.	1	Rain and snow.	64	—	—
" 25,	16	23	16	17.66	13	19	16	16	N.E.	2	S.E.	1	Fair.	61	—	—
" 27,	16	40	27	27.66	15	35	26	25.33	N.E.	1	N.E.	1	Fair.	75	—	—
" 28,	22	47	31	33.33	21	42	30	31	S.E.	1	S.E.	2	Fair.	72	—	—
" 30,	49	49	49	49	46	49	47	47.33	S.W.	2	S.	1	Rain.	72	—	—
Dec. 1,	40	44	33	39	38	40	31	36.33	N.	1	S.W.	1	Weather raw and damp.	76	—	—
" 2,	37	47	41	38.33	36	43	31	39.33	S.W.	1	S.E.	3	Fair.	76	—	—
" 3,	33	42	34	36.33	31	36	32	33	S.E.	2	S.E.	1	Fair.	79	—	—
" 4,	22	38	35	35	34	35	35	32.66	E.	1	S.E.	1	Cloudy; snow at 8 P.M.	80	—	—
" 7,	35	47	37	39.66	34	43	35	37.33	W.	1	S.E.	1	Fair; snow has entirely disappeared.	80	—	—
" 8,	38	51	48	45.66	37	49	47	44.33	W.	3	W.	6	Cloudy; fog at 7 A.M.	80	—	—
" 10,	35	39	33	35.66	32	35	32	38	S.	1	W.	1	Occasional sprinkles of snow.	80	—	—
" 11,	31	35	31	32.66	29	32	30	30.33	N.	0	N.	3	Cloudy.	80	—	—
" 12,	24	35	26	28.33	23	31	25	26.33	N.W.	1	S.W.	2	Fair; atmosphere hazy.	80	—	—
" 14,	26	47	33	33.33	23	43	32	33.33	N.	1	N.E.	1	Fair; atmosphere hazy.	80	—	—
" 15,	32	48	36	38.66	31	44	36	37					Fair; atmosphere hazy.	80	—	—

TABLE *showing the tenacity and density of specimens, from the heads, and from different parts of guns, those from corresponding parts of the different guns and heads being similarly marked.*

Number or Mark of Specimen.	No. 334. HOLLOW.		No. 335. SOLID.		No. 893. SOLID.	
	Density.	Tenacity.	Density.	Tenacity.	Density.	Tenacity.
H. C., . . .	—	—	7.157	23873	7.195	26873
H. 1, . . .	7.168	23815	7.134	23559	7.259	32816
H. 2, . . .	7.181	26883	7.136	26084	7.236	32752
H. 3, . . .	7.166	27548	7.140	24300	7.245	30027
G. 1, . . .	—	—	7.139	24567	7.235	30307
G. 2, . . .	—	—	7.133	22474	7.238	28019
G. 3, . . .	—	—	7.132	24703	7.193	28571
G. 4, . . .	—	—	7.130	22313	7.222	29965
G. 5, . . .	—	—	7.126	22229	7.249	.32938
G. 6, . . .	—	—	7.133	26176	7.270	30829
G. 7, . . .	—	—	7.134	25652	7.259	31743
G. 8, . . .	—	—	7.116	22996	7.265	31919
G. 9, . . .	—	—	7.135	23855	7.252	30873
Mean of H. 1, H. 2, and H. 3, .	7.172	26082	7.137	24648	7.247	31865
Mean of H. C., H. 1, H. 2, and H. 3,	—	—	7.142	24454	7.235	30616
Mean of Gun Specimens, . .	—	—	7.130	23885	7.242	30573

TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 in. long and 1.382 in. diameter, taken from near the surface of the bore of triplicate 10-inch Columbiad, No. 983, cast solid, at the West Point Foundry, in 1857.*

Weight per square inch of section.	Extension per inch in length.	Restoration per inch in length.	Permanent set per inch in length.
1000 lbs.	.0000357	.0000357	.0000000
2000	.0000714	.0000714	.0000000
3000	.0001200	.0001200	.0000000
4000	.0001742	.0001685	.0000057
5000	.0002171	.0002057	.0000114
6000	.0002828	.0002657	.0000171
7000	.0003314	.0003114	.0000200
8000	.0003743	.0003486	.0000257
9000	.0004371	.0004057	.0000314
10000	.0004771	.0004371	.0000400
11000	.0005800	.0005257	.0000543
12000	.0006629	.0005972	.0000657
13000	.0007400	.0006600	.0000800
14000	.0008086	.0007115	.0000971
15000	.0008943	.0007772	.0001171
16000	.0009914	.0008514	.0001400
17000	.0011288	.0009545	.0001743
18000	.0012657	.0010400	.0002257
19000	.0013715	.0011058	.0002657
20000	.0014943	.0011686	.0003257
21000	.0016600	.0012600	.0004000
22000	.0018685	.0013285	.0005400
23000	.0020885	.0014028	.0006857
24000	.0023628	.0015171	.0008457

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TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 in. long and 1.366 in. diameter, taken from near the exterior surface of triplicate 10-inch Columbiad, No. 983, cast solid, at the West Point Foundry, in 1857.*

Weight per square inch of section.	Extension per inch in length.	Restoration per inch in length.	Permanent set per inch in length.
1000 lbs.	.0000611	.0000611	.0000000
2000	.0000794	.0000794	.0000000
3000	.0001089	.0001089	.0000000
4000	.0001771	.0001771	.0000000
5000	.0002129	.0002129	.0000000
6000	.0002700	.0002686	.0000014
7000	.0003328	.0003299	.0000029
8000	.0003986	.0003943	.0000043
9000	.0004557	.0004486	.0000071
10000	.0005100	.0004991	.0000109
11000	.0005500	.0005343	.0000157
12000	.0006414	.0006251	.0000257
13000	.0007100	.0006800	.0000300
14000	.0007700	.0007343	.0000357
15000	.0008557	.0008080	.0000477
16000	.0009243	.0008714	.0000529
17000	.0010014	.0009371	.0000643
18000	.0010900	.0009886	.0001014
19000	.0012271	.0010800	.0001471
20000	.0013586	.0011572	.0002014
21000	.0015386	.0012486	.0002900
22000	.0017043	.0013057	.0003980
23000	.0019529	.0014000	.0005529
24000	.0022786	.0015257	.0007529
25000	.0026037	.0015194	.0010843
26000	.0032186	—	—

TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 in. long and 1.382 in. diameter, taken from near the surface of the bore of triplicate 10-inch Columbiad, No. 355, cast solid, at the Fort Pitt Foundry, in 1857.*

Weight per square inch of section.	Extension per inch in length.	Restoration per inch in length.	Permanent set per inch in length.
1000 lbs.	.0000600	.0000600	.0000000
2000	.0001343	.0001343	.0000000
3000	.0002057	.0002000	.0000057
4000	.0002657	.0002543	.0000114
5000	.0003257	.0003114	.0000143
6000	.0003800	.0003543	.0000257
7000	.0004514	.0004143	.0000371
8000	.0005314	.0004771	.0000543
9000	.0006171	.0005457	.0000714
10000	.0007114	.0006171	.0000943
11000	.0008114	.0006885	.0001229
12000	.0009229	.0008000	.0001629
13000	.0010743	.0008371	.0002372
14000	.0012429	.0009458	.0002971
15000	.0014086	.0011022	.0003857
16000	.0016371	.0011114	.0005257
17000	.0019571	.0012314	.0007257
18000	.0023143	.0013086	.0010057
19000	.0028257	.0014143	.0014114

TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 in. long and 1.382 in. diameter, taken from near the exterior surface of triplicate 10-inch Columbiad, No. 983, cast solid, at the Fort Pitt Foundry, in 1857.*

Weight per square inch of section.	Extension per inch in length.	Restoration per inch in length.	Permanent set per inch in length.
1000 lbs.	.0000429	.0000415	.0000014
2000	.0001086	.0001057	.0000029
3000	.0001714	.0001657	.0000057
4000	.0002343	.0002257	.0000086
5000	.0002943	.0002814	.0000129
6000	.0003543	.0003372	.0000171
7000	.0004200	.0003971	.0000229
8000	.0004886	.0004600	.0000286
9000	.0005571	.0005200	.0000371
10000	.0006314	.0005828	.0000486
11000	.0007029	.0006400	.0000629
12000	.0007943	.0007143	.0000800
13000	.0008943	.0007857	.0001086
14000	.0010114	.0008571	.0001543
15000	.0011428	.0009299	.0002129
16000	.0012714	.0009600	.0003114
17000	.0014914	.0010000	.0004914
18000	.0018114	.0011514	.0006600
19000	.0022772	.0012144	.0010628
20000	.0029000	.0013000	.0016000
21000	.0033657	—	—

TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder* 10 *in. long and* 1.382 *in. diameter, taken from near the surface of bore of triplicate* 10-*inch Columbiad, No.* 983, *cast solid, at the West Point Foundry, in* 1857.

Weight per square inch of section.	Compression per inch in length.	Restoration per inch in length.	Permanent set per inch in length.
1000 lbs.	.000100	.000100	.000000
2000	.000240	.000240	.000000
3000	.000310	.000300	.000010
4000	.000380	.000340	.000040
5000	.000435	.000375	.000060
6000	.000505	.000440	.000065
7000	.000540	.000475	.000065
8000	.000625	.000555	.000070
9000	.000670	.000540	.000130
10000	.000780	.000640	.000140
11000	.000850	.000700	.000150
12000	.000890	.000730	.000160
13000	.000965	.000790	.000175
14000	.001010	.000800	.000210
15000	.001095	.000875	.000220
16000	.001150	.000920	.000230
17000	.001240	.000990	.000250
18000	.001295	.001015	.000280
19000	.001345	.001055	.000290
20000	.001430	.001120	.000310
21000	.001490	.001150	.000340
22000	.001570	.001200	.000370
23000	.001620	.001230	.000390
24000	.001720	.001290	.000430
25000	.001790	.001320	.000470
26000	.001880	.001380	.000500
27000	.001955	.001415	.000540
28000	.002040	.001455	.000585
29000	.002105	.001485	.000620
30000	.002250	.001565	.000690

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TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder* 10 *in. long and* 1.382 *in. diameter, taken from near the exterior surface of triplicate* 10-*inch Columbiad, No.* 983, *cast solid, at the West Point Foundry, in* 1857.

Weight per square inch of section.	Compression per inch in length.	Restoration per inch in length.	Permanent set per inch in length.
1000 lbs.	.000090	.000090	.000000
2000	.000170	.000170	.000000
3000	.000255	.000250	.000005
4000	.000320	.000305	.000015
5000	.000385	.000360	.000025
6000	.000455	.000425	.000030
7000	.000505	.000470	.000035
8000	.000575	.000530	.000045
9000	.000645	.000590	.000055
10000	.000705	.000635	.000070
11000	.000790	.000680	.000110
12000	.000845	.000725	.000120
13000	.000905	.000775	.000130
14000	.000955	.000810	.000145
15000	.001035	.000865	.000170
16000	.001090	.000905	.000185
17000	.001165	.000955	.000210
18000	.001250	.001015	.000235
19000	.001335	.001065	.000270
20000	.001395	.001095	.000300
21000	.001485	.001150	.000335
22000	.001555	.001190	.000365
23000	.001655	.001250	.000405
24000	.001750	.001295	.000455
25000	.001825	.001330	.000495
26000	.001940	.001385	.000555
27000	.002050	.001440	.000610
28000	.002145	.001475	.000670
29000	.002250	.001515	.000735
30000	.002380	.002060	.000320

TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 10 in. long and 1.382 in. diameter, taken from near the surface of bore of triplicate 10-inch Columbiad, No. 335, cast solid, at the Fort Pitt Foundry, in 1857.*

Weight per square inch of section.	Compression per inch in length.	Restoration per inch in length.	Permanent set per inch in length.
1000 lbs.	.000145	.000145	.000000
2000	.000225	.000225	.000000
3000	.000305	.000300	.000005
4000	.000375	.000360	.000015
5000	.000465	.000440	.000025
6000	.000530	.000485	.000045
7000	.000615	.000560	.000055
8000	.000695	.000610	.000085
9000	.000755	.000660	.000095
10000	.000825	.000695	.000130
11000	.000895	.000730	.000165
12000	.000985	.000800	.000185
13000	.001055	.000850	.000205
14000	.001125	.000875	.000250
15000	.001220	.000955	.000265
16000	.001305	.001000	.000305
17000	.001415	.001065	.000350
18000	.001510	.001115	.000395
19000	.001595	.001165	.000430
20000	.001710	.001215	.000495
21000	.001830	.001275	.000555
22000	.001955	.001315	.000640
23000	.002090	.001370	.000720
24000	.002240	.001430	.000810
25000	.002380	.001475	.000905
26000	.002540	.001475	.001065·
27000	.002780	.001565	.001215
28000	.003010	.001655	.001355
29000	.003295	.001770	.001525
30000	.003490	.001720	.001770

TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 10 in. long and 1.382 in. diameter, taken from near the exterior surface of triplicate 10-inch Columbiad, No. 335, cast solid, at the Fort Pitt Foundry, in 1857.*

Weight per square inch of section.	Compression per inch in length.	Restoration per inch in length.	Permanent set per inch in length.
1000 lbs.	.000075	.000075	.000000
2000	.000155	.000150	.000005
3000	.000205	.000195	.000010
4000	.000265	.000250	.000015
5000	.000355	.000335	.000020
6000	.000465	.000430	.000035
7000	.000545	.000490	.000055
8000	.000625	.000550	.000070
9000	.000685	.000600	.000085
10000	.000770	.000665	.000105
11000	.000835	.000705	.000130
12000	.000895	.000745	.000150
13000	.000970	.000800	.000170
14000	.001055	.000855	.000200
15000	.001140	.000905	.000235
16000	.001230	.000960	.000270
17000	.001310	.000995	.000315
18000	.001385	.001030	.000355
19000	.001485	.001085	.000400
20000	.001575	.001130	.000440
21000	.001690	.001175	.000515
22000	.001815	.001225	.000590
23000	.001935	.001275	.000660
24000	.002060	.001330	.000730
25000	.002200	.001360	.000840
26000	.002350	.001385	.000965
27000	.002560	.001455	.001105
28000	.002765	.001480	.001285
29000	.003035	.001505	.001530
30000	.003410	.001520	.001890

RECAPITULATION.

Powder, Dupont's make, of 1857.

Mean range by eprouvette, 295 = 300 yards.

Range of proof charges, —

1st fire,	.	.	.	.	.	.	.	311 yards.
2d "	.	.	.	.	.	.	.	312 "

Proof Charges.

1st fire, 20 lbs. powder, 1 solid shot, 1 sabot and 1 wad.

2d fire, 24 lbs. powder, 1 shell and sabot.

Service Charges.

14 lbs. powder, 1 solid shot, and 1 sabot.

Number of Rounds Endured.

Gun No. 983, West Point solid 169, burst.

Gun No. 335, Fort Pitt solid 399, burst.

Gun No. 334, Fort Pitt hollow 1600, unbroken.

As far as the experiments have gone in bursting hollow cylinders by internal pressure exerted upon different lengths of bore, they confirm, in a most striking manner, the theory on that subject, as given in my last Report; and indicate that the thickness of metal in rear of the bottom of the bore, in guns without chambers, should not be less than one and three-fourths calibre.

I have been ably and diligently assisted in the proof and mechanical tests of these guns, by Lieut. J. W. Sill, of the Ordnance Department.

(Signed,)   T. J. RODMAN,

Capt. of Ordnance.

I concur in the foregoing Report, so far as it embraces the period of my association with Capt. T. J. Rodman, in the experiments on the trial Columbiads Nos. 334, 335 and 983.

J. W. SILL,

Lieut. of Ordnance.

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REPORT

ON THE

CAUSES OF DIFFERENCE IN THE ENDURANCE OF CANNON

WHEN CAST SOLID, AND CAST HOLLOW,

COOLED

FROM THE

EXTERIOR AND THE INTERIOR.

REPORT

CAUSES OF DIFFERENCE IN THE ENDURANCE OF CANNON, WHEN CAST SOLID, AND CAST HOLLOW, COOLED FROM THE EXTERIOR AND THE INTERIOR.

ALLEGHANY ARSENAL, *November* 30, 1851.

COL. H. K. CRAIG, ORDNANCE OFFICE, }
    WASHINGTON, D. C. }

SIR: Although Major Wade will furnish you with a Report in full of the manufacture and proof of the experimental 8 and 10-inch guns, recently made at the Fort Pitt Works, yet I deem it proper to submit what I consider to be the causes of the very marked differences in the endurance of these guns; and, in order to render these causes more apparent, it will be necessary to consider the law governing the strain produced on any material by the action of a central force, as well as the consequences which flow therefrom.

Barlow shows that the strain produced on any material, by the action of a central force, diminishes as the square of the distance from the centre increases.

His demonstration is based upon the hypothesis that the area of the cross section of the body to which the force is applied remains the same before and after the application of the central force. So that, if $r =$ radius of bore, $R =$ radius of exterior, $b =$ increase of interior radius, and $B =$ that of exterior radius, we shall have the equation $\pi (R^2 - r^2) = \pi (R + B)^2 - (r + b)^2$, or $R^2 - r^2 = R^2 + 2BR + B^2 - r^2 - 2rb - b^2$; but since (B) and (b) are very small fractions of (R) and (r), their squares may be neglected, and

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we shall have $BR = br$ (3). But the strain produced on any two pieces of the same material will be proportional to the increase in length divided by the original length of each respectively, — the absolute strain, for a given increase in length, depending on the coefficient of elasticity of the material strained; so that if $\dfrac{B}{R}=$ strain on the exterior, then $\dfrac{b}{r}=$ that on the interior; but if, in equation (3), we multiply and divide the 1st member by R, and the 2d by r, we shall have $R^2\,\dfrac{B}{R}=r^2\,\dfrac{b}{r}$, or the proportion $R^2 : r^2 :: \dfrac{b}{r} : \dfrac{B}{R}$, or the strain diminishes as the square of the distance from the centre increases.

Now let us suppose a gun perfectly free from strain, and apply a central force until the interior is brought to the breaking strain; and let the radius of the bore be the unit of measure, and $a =$ tensile strength of the square unit. Then, if the gun be one calibre in thickness, the distance from the centre of the bore to the exterior will be 3, and the strain will diminish in obedience to the above demonstrated law, until that at the exterior will be 1-9th of that at the interior, and the effective resistance which the gun will be capable of offering to a central force will be the sum of all these strains.

In order to determine this sum, let it $= u$, and let $x =$ any variable distance from the centre, and we shall have, for the strain upon any one of the infinitely thin cylinders of which the thickness of the gun is composed, $a\,\dfrac{dx}{x^2}$, and for the sum of all these strains, $u = a\displaystyle\int \dfrac{dx}{x^2} + c = -\,\dfrac{a}{x} + c$; now, to determine the value of (c), let $u = o$, and $x = 1$, (since when $x = 1$, the sum of the strains $= o$), and we find $c = a$, and $u = -\,\dfrac{a}{x} + a$; and integrating between the limits $x = 1$, and $x = 3$, we have $u = a - \dfrac{a}{3} = \dfrac{2}{3}\,a$; or, the effective resistance of a gun one calibre in thickness will be two-thirds ($\frac{2}{3}$) of that which half a calibre in thickness would offer, if the strains were all equal as in the tensile strain.

The above results suppose the gun to be entirely free from strain before the application of the straining force, a condition which could only be obtained by allowing it an infinite length of time to cool.

For it never could cool without allowing the surface to fall to a temperature below that of the interior of the metal; and, since iron diminishes in bulk as its temperature decreases, it follows that a gun cast solid, and cooled,

of necessity, from the exterior and in a limited time, will be thrown upon a strain — the exterior being under a force of compression, while the interior is under one of elongation ; and the greater the difference of temperature between the exterior and interior, during the process of cooling, or the more rapidly the cooling is effected, the greater will be this strain.

Now, let us suppose a central force applied to a gun thus strained, and bear in mind the law of strain, as above demonstrated : the interior is already under a force of elongation, while the exterior is under one of compression : the action of the central force develops (in a gun, one calibre thick) nine times the strain on the interior that it does on the exterior, independent of previous strain ; so that we have the effort of the exterior to free itself from the force of compression to which it has been subjected in cooling, combined with the central force, to break the interior ; and the wonder is, that guns thus strained, in cooling, endure as long as they have been found to do.

It is also known that the contraction of iron, under equal degrees of reduction in temperature, increases as the iron approaches a state of purity ; or, as the percentage of carbon diminishes ; so that what is termed very high iron cannot be cast into shapes — where the times of cooling of the different parts are unequal — with any certainty of enduring the strain to which it is thus subjected, and large rolls for rolling iron have been known to split open, longitudinally, from this cause.

Now the iron of which the experimental guns were made was what is termed *high* iron, all of it having been melted once and run out into pigs, and a portion of these pigs again re-melted, before being melted for casting the guns ; this degree of purity having been found to produce the greatest tensile strength attainable with this iron, without risk of cavities in the castings.

This iron contracted more, in cooling, than that which we have been in the habit of using at this foundry ; as shown by the fact, that the 8-inch guns cast from it, and off the same pattern as heretofore used, were from .10 to .15 of an inch less in diameter than those from other iron. The small endurance of the 8-inch solid gun can only be explained or accounted for by reference to the above stated laws, deductions, and facts.

These, to my mind, do satisfactorily account for the early bursting of the solid gun, and for the greater endurance of the hollow one ; for the same

causes which contributed to the bursting of one, *being reversed in effect*, contributed to the endurance of the other.

The solid gun, cooling from the exterior in an open pit, and being of iron that contracted very much in cooling, was doubtless thrown upon a very heavy strain, the exterior being compressed, and the interior elongated; while the hollow gun, being rapidly cooled from the interior, and prevented from cooling from the exterior, was thrown upon a strain just the reverse of the solid one. And I have no doubt that the interior of the solid gun was broken *before* the exterior was relieved from the pressure to which it had been subjected in cooling; while in the hollow gun, the great object of my improvement was in part, if not fully, attained, — viz., to throw the gun upon a strain, such, that under the action of the law of strain, as stated above, each one of the infinitely thin cylinders composing the thickness of the gun shall be brought to the breaking strain at the same instant.

This condition would give us for the effective resistance to rupture, in a gun 1 calibre thick, 2 a, instead of $\frac{2}{3}$ a — which has been shown to be all that could be obtained from a gun free from strain by cooling — and is, doubtless, *much more* than can possibly be attained in practice. The higher the metal, and the greater its contraction in cooling, and the more rapidly the gun is cooled, the further will the solid one fall below $\frac{2}{3}$ a, and the more nearly will the hollow one approach 2 a, provided the cooling be effected from the interior; also, the greater the diameter of the solid gun, the greater will be the strain from cooling. It is not considered practicable to cool a gun so rapidly from the interior as to cause rupture to commence on the exterior.

The less endurance of the 10-inch hollow gun than that of the 8-inch hollow one, is accounted for by the fact, that the 10-inch gun had no fire on the exterior of the flask while cooling, it having been rammed up in the pit, where it was supposed, at the time of casting, that the heat of the gun would be retained by the sand, until the interior would be cooled by the circulation of water through the core barrel.

This supposition was found to be erroneous on digging out the sand, as its temperature was found to be much lower than had been expected.

The less endurance of the 10-inch solid gun than that of the 8-inch solid gun, is attributable to the increased strain to which it was subjected in cooling, arising from its increased diameter; and to the greater pressure of

the gas in firing, which is, directly, as the diameter of the bore; since the weight of the shot increases as the cube of the diameter, while the area of its great circle, or the surface pressed, only increases as the square of the diameter.

The 10-inch guns were both rammed up in the same pit for casting. They were thus treated on account of the smallness of the flasks, it having been considered unsafe to cast without this precaution; as it was feared that the great body of heat in these guns would strike through the small thickness of sand, and weaken the flasks so much as to cause them to give way, and let the metal out of the moulds.

The flask being rammed up in the pit, of course rendered it impossible to apply heat to the exterior, during the process of cooling. So that I do not consider my mode of cooling to have been properly applied in this case (although is was intended to be, at the time of casting), nor do I consider the endurance of this gun as any criterion, or measure, of what can be attained by a proper application of the new mode of cooling; though it certainly does show that, as far as this mode was applied, it was beneficial, as the ratio of endurance of the *pair* is about $12\frac{1}{2}$ to 1 in its favor. I have the utmost confidence that with iron of the same quality as that used in these guns, and a proper application of the new mode, a 10-inch gun may be made to endure from 1000 to 1250 fires.

I am, very respectfully, Sir,

Your obedient servant,

T. J. RODMAN.

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REPORT

FABRICATION AND PROOF, UP TO 2450 SERVICE CHARGES EACH,

OF 2 10-INCH TRIAL GUNS;

ONE CAST SOLID, AND COOLED FROM THE EXTERIOR,

AND THE OTHER CAST HOLLOW, AND COOLED FROM THE INTERIOR.

REPORT

FABRICATION AND PROOF, UP TO 2450 SERVICE CHARGES EACH, OF 2 10-INCH TRIAL GUNS; ONE CAST SOLID, AND COOLED FROM THE EXTERIOR, AND THE OTHER CAST HOLLOW, AND COOLED FROM THE INTERIOR.

THESE guns were cast at the Fort Pitt Foundry, from the remainder of the iron selected by Lieut. F. J. Shunk and myself, on the 2d and 3d of July, 1857, at the West Point Foundry, and sent to the Fort Pitt Foundry.

They were cast on the 11th of August, 1858, one (No. 362) hollow, and the other (No. 363) solid.

Of the Iron.

The iron was melted in the same furnaces which were used in casting the first pair of 10-inch guns from the selected iron, in August, 1857, and used in the same proportion, and similarly distributed among the three furnaces, the marks on every pig being still perfectly distinct.

Charges and Distribution of Metal.

KIND OF IRON USED.	QUANTITY OF IRON CHARGED.			
	Furnace No. 1.	Furnace No. 2.	Furnace No. 3.	Total charged.
Greenwood pig, No. 1, ...	3685 lbs.	4819 lbs.	5670 lbs.	14174 lbs.
" " No. 2, ...	4532 "	5926 "	6972 "	17430 "
" " No. 3, ...	1870 "	2445 "	2577 "	7192 "
Salisbury pig, ...	2047 "	2677 "	3150 "	7874 "
Scotch "	409 "	535 "	630 "	1574 "
Re-melted in the above proportion, .	1045 "	1368 "	1610 "	4023 "
Total charge, ...	13588 lbs.	17770 lbs.	20909 lbs.	52267 lbs.

Condition of Pits.

The pits in which the guns were cast were in good condition, having had a strong fire burning in them from the 3d to the 7th inst., previous to casting; they were cleaned out on the 9th, and fresh fuel was placed on the grate bars, preparatory to casting.

Preparation of Moulds.

The moulds in which these guns were cast were formed in the same flasks in which the guns from the same iron of the previous year were cast; that for the solid gun was prepared on the 6th, and placed in the pit on the 9th; that for the hollow gun was prepared on the 9th, and placed in the pit on the 10th.

The furnaces were charged on the 10th, each furnace receiving the different kinds of iron in the same proportion as for casting the 10-inch trial guns, Nos. 334 and 335, of 1857.

Casting.

The furnaces were all lighted at 9h. 10m. A. M., on the 11th August, 1858.

The metal in all the furnaces was melted at 1h. 30m. P. M. The furnaces were tapped, No. 3 at 3h. 2m., No. 2 at 3h. 7m., and No. 1 at 3h. 12m. P. M.

The metal from all the furnaces was received in the same vessel, which was furnished with two orifices, from which the flow of the metal could be regulated at will. The metal flowed from both orifices at the same time, and was conducted by runners into the gun moulds, which were filled simultaneously in 12 minutes after the first metal entered. The metal flowed from only one furnace at the same time.

The pits were closely covered with iron covers, and the fuel in that which contained the mould for the solid gun ignited while casting, and that in the hollow gun-pit was fired immediately after casting.

The metal entered the moulds by side runners till they were filled above the trunnions, then directly at their mouths, till filled.

Cooling.

Water circulated through the core barrel of the hollow gun at the rate of about three cubic feet per minute, from the time the metal reached the bottom of the core in casting, till the casting was cold.

At 20 minutes after casting, water entered at 80° and left at 102°.

Cooling Table.

HOURS AFTER CASTING.	Entered at	Left at
2, ...	80°	100°
5, ...	80	96
7, ...	80	94
9, ...	80	93
11, ...	80	92
13, ...	80	92
15, ...	80	91
16, ... , .	80	90

At 16 hours after casting the core barrel was removed, and water, at the same rate as before, circulated through the cavity thus left. Just after the removal of the core barrel, water left at 144°.

Cooling Table—Continued.

HOURS AFTER CASTING.	Entered at	Left at	HOURS AFTER CASTING.	Entered at	Left at
17, ...	80°	144°	39, ...	80°	92°
19, ...	80	134	41, ...	80	92
21, ...	80	108	43, ...	80	91
23, ...	80	105	45, ...	80	90
25, ...	80	103	53, ...	80	89
27, ...	80	99	57, ...	80	87
29, ...	80	97	61, ...	80	86
31, ...	80	96	63, ...	80	85
33, ...	80	94	73, ...	80	84
35, ...	80	93	75, ...	80	83
37, ...	80	92	81, ...	80	81

Water continued to circulate through the hollow cast gun till 9h. 30m. A. M., on the 19th, at which time it entered and left at the same temperature.

Temperature of the Pits.

Hours after Casting.							Temperature of Solid Pit.	Temperature of Hollow Pit.
2,	.	.	.	.	.	.	160°	350°
6,	.	.	.	.	.	.	350	600
19,	.	.	.	.	.	.	460	About 900
40,	.	.	.	.	.	.	472	" 900
75,	.	.	.	.	.	.	360	315
125,	.	.	.	.	.	.	150	100
155,	.	.	.	.	.	.	125	96

No fuel was added to the solid gun-pit after casting; and none to the hollow gun-pit after 46 hours after casting; from which time the fire gradually went down. The guns were both entirely cold before they were removed from the pits.

The hollow gun was first removed from the pit, and was sufficiently cold for removal at least two days before it would have been proper to remove the solid cast gun.

Both moulds were formed on the same pattern; yet the hollow cast gun was between .3 and .4 inches less in diameter at the breech than the solid cast gun.

The difference in the appearance of the newly turned surfaces of the two guns was quite marked; the hollow gun presenting a rather fine and very regularly mottled surface, while the solid gun presented a clouded or dappled appearance.

The original programme, of which the trial of these guns is a part, contemplated that, at the same time this pair of guns was cast, the proprietor of the West Point Foundry would have cast, from the metal selected and left there for that purpose, a solid 10-inch gun; but at the time the order for casting these guns was under consideration, the proprietor of the West Point Foundry advised the Department and myself that a portion of the iron selected had been used, and that, in his judgment, it would be going against the light of experience to make another gun of the same iron which had been used in that of the previous year.

The programme has consequently not been followed.

These guns were accurately measured after completion, and found to be within the prescribed limits of variation in all their dimensions, except the

trunnions, which were not turned, owing to the fact that the trunnion lathe at the Fort Pitt Foundry had been so much injured by the then recent fire that it could not be put in working order in time to secure the proof of the guns during the then coming fall. No defect was discoverable on any part of either gun.

The proof charges were fired from these guns on the 2nd of October, when they were suspended for firing with service charges. The proof, with service charges, was continued up to the 24th of December, 1858.

The guns were fired alternately with charges of the same eprouvette range, each barrel of powder used being one-half fired from one gun, and the other half from the other gun.

Solid shot were used in all cases except one proof charge, and were rejected as soon as found to pass through the small gauge.

Proof Charges.

1st fire, 20 lbs. powder, one shot and sabot, and one wad.

2d fire, 24 lbs. powder, one shell and sabot.

The shells used in proof were neither of them perceptibly injured, although fired into a bank of moderately hard, shaly rock.

Service Charges.

The service charges used were 14 lbs. of powder, one solid shot and sabot; and of these charges 2396 rounds have been fired from each gun.

Also, 13 rounds with 18 lbs. powder,

15 " " 17 " "

14 " " 16 " "

And 12 " " 15 " " making a

Total of 2450 rounds, exclusive of proof charges.

Of the Powder.

There have been used in the proof of these guns,

142 barrels of Dupont's make of 1856,

And 95 " " " " " 1857.

The other powder used was all of Dupont's make, but of different dates, from 1837 to 1846, and received at this Arsenal in 1852 from the St. Louis Arsenal.

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The proof charges were from the 1857 powder, and from the small enlargement of the guns after proof, and from the low eprouvette range of this powder when tested in the old eprouvette mortars at this Arsenal, also, from the fact that some barrels were found to be badly caked, it was apprehended that the powder had deteriorated since last year.

In order to test this point, powder of the same make and same date (1857), but stored, some at Dupont's mills and some at the New York Arsenal, was sent here for comparison.

These powders have all been compared in both the old eprouvette and in a new one recently received at this Arsenal; and for pressure, velocity, and recoil in the 42-pdr. gun, with the results recorded in the following table :—

KINDS OF POWDER.	No. of Fires.	Mean Velocity.	Mean pressure of gas, per square inch.	Mean recoil of gun.	Range by old Eprouvette.	Range by new Eprouvette.
Dupont's, 1857, stored at New York Arsenal.	2 5 4	— 1370 ft. —	— — 40546 lbs.	— 22° 31′ —	— 230 yds. —	288 yds. — —
Dupont's, 1857, stored at Dupont's Mills.	4 2 5	— — 1360 ft.	40863 lbs. — —	— — 22° 37′	— — 238 yds.	— 289 yds. —
Dupont's, 1846, received from St. Louis Arsenal in 1852.	2 4 5 —	— 1340 ft. — —	— 38818 lbs. — —	— — — 22° 08′	— — — 256 yds.	304 yds. — — —
Dupont's, 1857, stored at Alleghany Arsenal.	3 5 2 4	1322 ft. — — —	— — — 40740 lbs.	— 22° 28′ — —	— 237 yds. — —	— — 273 yds. —
Dupont's, 1856, stored at Alleghany Arsenal.	3 5 2	— 1321 ft. —	36244 lbs. — —	— 22° 33′ —	— 222 yds. —	— — 290 yds.

The charges of powder used in the 42-pdr., giving the above results, were 10 lbs. each, and one solid shot without sabot. Pressures were determined by the method of indentations, and recoils were measured on an arc of 26′ feet radius. The velocities recorded in the foregoing table were determined by means of M. Navez' electro-ballistic pendulum. One wire passed just in front of the muzzle, and the other at 60 feet from it.

The following table compares the ranges of the same barrel, of the different

kinds of powder, obtained from the new eprouvette, with those marked on the barrels, at the time the powder was received.

KINDS OF POWDER.	Ranges marked on bbls.	Ranges by new Eprouvette.
Dupont's, 1856, ...	312 yards.	290 yards.
" 1857, ...	299 "	273 "
" " stored at mills, . .	269 "	289 "
" " stored at New York, .	299 "	288 "
" 1846, stored at St. Louis, .	266 "	304 "

The range marked on the barrel of 1846 powder, stored at St. Louis, is believed to be that obtained in its proof at this Arsenal just after its reception from the St. Louis Arsenal in 1852.

It appears from the above table, either that the eprouvettes contradict each other, or that the powder of 1857, stored at Dupont's mill, has improved in strength, while that of the same date and make, stored at the New York and Alleghany Arsenal, has deteriorated since the original proof.

It also appears that the oldest powder stored, since its reception at this Arsenal, in the same magazine with the powder of 1857, is the strongest powder of all.

The following velocities and recoils were obtained from the 10-inch solid gun with the same instrument, and are for measuring recoil, as used in obtaining the results recorded in the foregoing table. One solid shot and sabot were used in these trials, at each fire. Powder used, — Dupont's, 1846 ; received from St. Louis Arsenal.

Number of Fires.	Weight of Charge.	Mean Velocity.	Mean Recoil.
4	14 lbs.	940 feet.	—
5	—	—	24° 27'
5	15 lbs.	—	25° 09'
4	—	980 feet.	—
5	16 lbs.	971 feet.	26° 11'
4	17 lbs.	1022 feet.	—
5	—	—	26° 48'
5	18 lbs.	1044 feet.	26° 57'

Difference in Velocity of Shot due to Different Amounts of Enlargement in the two Guns.

In order to determine the difference, if any, in velocity of shot and recoil of gun, due to the greater enlargement, by firing, of the bore of the solid than of that of the hollow gun around the seat of the charge, a sufficient quantity of St. Louis powder for 20 cartridges of 14 lbs. each, was well mixed together and made into cartridges.

These cartridges were fired, 10 from each gun, with one solid shot and sabot. The velocities and recoils of the first five fired from the solid gun, and of the last five fired from the hollow gun, were determined, and are recorded in the following table :—

NUMBER OF FIRES.		VELOCITIES.		RECOILS.	
Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
1	1	1063	958	24° 14′	24° 39′
2	2	1006	*1326	24 22	24 30
3	3	872	998	25° 04′	24° 05′
4	4	927	788	25 02	24 23
5	5	1106	1016	24 53	24 40
Mean, ...		995	940	24° 43′	24° 27′
Mean of last rounds, .		968	934	25 00	24 24

* This result is evidently erroneous, and is neglected.

The last three rounds, from the hollow gun, were made with the same shot with which the five rounds, for velocities and recoils, were made from the solid gun. The mean of the last three rounds is therefore regarded as more nearly correct than the mean of the whole five rounds, as regards the information sought.

Either mean, however, leaves no doubt of the fact, that both velocity of shot and recoil of gun are considerably less in the solid than in the hollow gun, and this difference can be attributed to nothing but the greater windage, from wear and enlargement in firing, in the solid than in the hollow gun.

All the firing, for velocities and recoils, except the five rounds with the

hollow gun, whose results are recorded in the foregoing table, was made with the solid gun.

In order further to test the regularity of results obtained from the electro-ballistic pendulum, and from the hollow gun, eight rounds more of 14 lbs., one shot and sabot, were fired from that gun, with the results recorded in the following table:—

Number of Fires.	Weight of Charges.			Velocity of Shot.	Recoil.
1	14 lbs.			877 feet.	24° 41′
2	14 "			993 "	25 17
3	14 "			1020 "	25 10
4	14 "			1026 "	25 15
5	14 "	Dupont's of 1846, received from St. Louis Arsenal.		°1230 "	25 12
6	14 "			°1985 "	25 00
7	14 "			1009 "	24 39
8	14 "			1088 "	25 09
Mean				1001 feet.	25° 03′

° Target wire cut by sabot; result neglected.

These results give additional proof of the greater velocity and recoil obtained from the hollow than from the solid gun, with equal charges, and give the velocity of the 10-inch solid shot with 14 lbs. powder, equal in round numbers to 1000 feet per second.

Difference in Pressure of Gas and Velocity of Shot due to Different Amounts of Windage around the Shot.

For the purpose of determining the effect of windage upon the pressure of gas and velocity of shot, three shot were prepared; one was spherical, with a windage of 18 inches, one was ground off on one side so as to give a wind-age of 3 inches, and the other was ground in like manner so as to give 4 inches windage.

These shots were placed in the gun so that their flattened sides were directly upward; being secured in this position to the cartridge, and fired with 10 lbs. charges of the same quality of powder, from 42-pdr. gun, all accurately weighed, with the following results:—

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Number of Fires.	Windage.	Pressure.	Velocity.	Recoil.
1st,	.4 inch,	39184	failed.	22° 13′
4th,	.4 "	37751	1231 feet.	22 10
7th,	.4 "	37751	failed.	21 57
10th,	.4 "	37751	1318 feet.	22 10
13th,	.4 "	37511	1324 "	22 08
Mean, ...		37989	1291 feet.	22° 09′
2nd,	.3 inch,	39184	1300 feet.	22° 20′
5th,	.3 "	38228	1231 "	22 14
8th,	.3 "	38706	1220 "	22 12
11th,	.3 "	38228	1329 "	22 01
14th,	.3 "	41090	1312 "	22 13
Mean, ...		39087	1278 feet.	22° 12′
3rd,	.18 inch,	39184	1401 feet.	22° 15′
6th,	.18 "	41096	1324 "	21 53
9th,	.18 "	40618	1352 "	22 25
12th,	.18 "	37511	failed.	22 05
15th,	.18 "	37751	1272 feet.	22 03
Mean, ...		39232	1337 feet.	22° 08′

Taking into view all the foregoing results, it would appear that the powder used in the proof of this pair of guns does not differ materially from that used in the proof of the triplicate 10-inch guns of 1857.

The arc of recoil, which is doubtless the most reliable indication of projectile force, differs but slightly in all the five kinds of powder tested.

The powder of 1857, stored at Alleghany Arsenal, in the old magazine, where it was most likely to be injured, gives a maximum pressure almost identical with that of the same date and make, whether stored at Dupont's mills or at New York Arsenal, and greater than that of 1846, received from St. Louis Arsenal, or that of 1856, stored at this Arsenal in the new magazine; while the last named powders give the greatest eprouvette ranges of all.

The difference in endurance between the guns of 1857 and those of 1858 must, I think, be attributed to some other cause than the difference in quality of the powder used in these proofs.

Mechanical Tests.

Specimens were taken from the heads of these guns and tested for tensile strength and specific gravity, with the following results :—

TABLE *of Tensile Strength, and Density of Head Specimens.*

FROM WHAT POSITION TAKEN.	TENSILE STRENGTH.		DENSITY.	
	Hollow.	Solid.	Hollow.	Solid.
H. No. 363, from axis, ...	—	19592	—	7.122
H. No. 363, II., from near surface of bore, .	—	26225	—	7.168
H. No. 363, M., middle of thickness, . .	—	26177	—	7.159
H. No. 363, O., outer surface, . . .	—	25412	—	7.150
H. No. 362, II., inner surface, . . .	27034	—	7.201	—
H. No. 362, M., middle of thickness, . .	29178	—	7.210	—
H. No. 362, O., outer surface, . . .	26986	—	7.192	—
Mean, ...	27733	26038	7.201	7.159

Enlargement of Bores by Firing.

These guns are both remarkable in this particular, having enlarged less with a given number of rounds than any guns of this calibre that I have proved.

The hollow gun of 1857 had an enlargement at 1600 rounds = .133 in., while the hollow gun of 1858, after 1628 rounds, has an enlargement = .100 in.

The following table shows the enlargement of the bores of the guns of 1858, in thousandths of an inch, after the number of rounds therein stated :—

TABLE *showing Enlargements of Bores above their original Diameters, after the under-mentioned numbers of Fires, in thousandths of an Inch.*

Distance from Muzzle.	DIAMETER OF BORES BEFORE PROOF.		AFTER PROOF.		25TH FIRE.		48TH FIRE.		83RD FIRE.	
	Hollow Gun.	Solid Gun.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
10 in.	10.001 in.	10.005 in.	1	2	0	0	2	1	2	3
20	10 002	10.004	1	1	—1	—1	1	1	2	3
30	10.001	10.004	1	1	0	0	1	2	2	3
40	10.001	10.003	—1	1	0	1	0	3	1	3
50	10.001	10.002	—1	1	1	2	1	3	3	4
60	10.001	10.002	—1	2	0	1	0	3	2	3
70	10.001	10.001	0	3	—1	2	—1	4	1	5
80	10.001	10.000	—1	2	—1	3	—1	4	0	4
81	10.001	10.000	0	3	—1	3	—1	4	0	5
82	10.001	10.000	—1	3	—1	4	—1	4	0	5
83	10.001	10.000	—1	3	—1	6	—1	4	0	8
84	10.001	10.000	—1	3	—1	5	—1	6	0	9
85	10.000	10.000	0	3	0	5	1	6	1	6
86	10.001	10.000	—1	3	—1	5	0	8	0	9
87	10.001	10.001	0	3	—1	4	0	5	0	7
88	10.001	10.000	—1	4	0	6	0	7	0	10
89	10.000	10.000	0	5	1	8	3	9	2	12
90	10.000	10.000	0	7	2	11	2	13	4	19
91	10.000	10.000	1	15	2	12	3	13	3	20
92	10.000	10.000	2	17	2	16	1	17	3	18
93	10.000	10.000	3	15	1	14	2	15	0	18
94	10.000	10.000	2	11	1	13	2	16	5	19
95	10.000	10.000	1	9	2	15	2	19	4	20
96	10.000	10.000	1	9	1	13	2	15	3	18
97	10.000	10.000	0	7	0	10	2	11	2	13
98	10.000	10.000	0	7	0	9	1	10	1	11
99	10.001	10.000	1	6	1	8	1	10	1	10
100	9.999	10.000	1	6	1	8	1	9	1	10
101	9.999	10.000	0	6	1	7	1	8	1	9
102	9.992	9.992	0	8	1	8	0	9	1	9

Enlargements of Bores—Continued.

Distance from Muzzle.	118TH FIRE.		153RD FIRE.		193RD FIRE.		238TH FIRE.		238TH FIRE, 24 hours after.		284TH FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
10 in.	1	2	1	0	1	—1	Gun warm. 2	2	1	1	2	1
20	0	1	0	0	0	1	3	3	1	2	1	2
30	1	1	1	1	2	0	3	3	2	1	3	3
40	0	1	2	3	2	3	3	7	1	2	2	4
50	0	3	1	2	1	2	3	3	1	3	2	3
60	1	1	0	2	0	2	2	4	1	4	2	4
70	—1	3	0	4	0	6	3	8	3	5	2	7
80	0	4	0	5	—1	4	1	5	0	4	1	5
81	0	4	0	5	—1	4	2	5	0	6	1	6
82	—1	6	0	5	—1	4	1	8	0	7	0	6
83	—1	6	—1	5	—1	4	0	9	0	7	0	9
84	—1	7	—1	6	—1	5	0	9	0	8	0	9
85	0	9	0	7	0	7	2	9	2	8	2	11
86	—1	9	1	7	0	9	1	9	1	8	1	11
87	—1	4	1	7	0	7	1	8	1	8	1	9
88	—1	10	2	11	0	11	1	11	3	12	2	15
89	0	13	2	18	3	17	3	19	5	19	4	19
90	2	18	1	20	4	20	5	21	5	21	5	21
91	0	17	3	23	2	23	4	21	4	19	4	23
92	2	14	4	19	3	20	6	20	6	17	8	22
93	4	18	6	23	7	24	11	25	10	21	12	26
94	4	21	4	25	7	25	10	29	9	24	11	30
95	5	24	4	27	4	27	7	30	5	25	7	32
96	3	18	2	20	3	20	5	23	4	19	5	22
97	1	12	1	14	2	13	4	15	3	14	3	15
98	2	9	1	9	2	10	3	9	2	11	2	12
99	0	9	0	9	0	9	1	10	0	9	1	9
100	1	8	1	9	2	8	2	9	2	8	3	9
101	1	7	1	7	1	8	3	8	1	8	2	8
102	0	8	2	8	0	7	3	8	1	8	3	8

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Enlargements of Bores—Continued.

Distance from Muzzle.	329TH FIRE.		374TH FIRE.		424TH FIRE.		474TH FIRE.		524TH FIRE.		574TH FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
10 in.	1	2	1	1	1	2	2	2	3	2	3	3
20	0	3	0	1	1	4	1	4	2	4	3	5
30	2	1	2	1	3	3	2	2	4	4	3	4
40	2	5	1	3	2	5	2	6	4	6	4	6
50	2	2	1	3	2	3	2	3	2	5	3	5
60	2	3	1	4	2	5	1	7	3	7	2	5
70	3	5	2	7	2	8	3	7	2	7	3	8
80	1	6	0	5	0	5	1	5	2	7	1	8
81	0	6	1	6	0	5	1	6	1	7	2	8
82	0	8	1	8	0	6	1	6	1	8	1	9
83	0	8	0	8	0	8	1	9	1	9	1	10
84	0	8	0	11	1	13	1	13	1	14	1	12
85	1	10	1	12	3	15	2	15	3	16	2	14
86	0	11	0	10	1	12	1	13	2	13	2	13
87	0	9	0	7	1	9	1	9	2	10	2	12
88	0	15	1	14	2	15	2	16	3	14	3	20
89	3	19	3	19	4	20	6	22	7	20	7	22
90	5	21	6	21	6	21	7	22	9	23	8	23
91	4	24	3	25	5	25	5	26	7	23	7	28
92	5	23	9	20	10	25	13	29	15	33	18	33
93	13	30	18	32	22	37	24	48	30	45	40	70
94	17	43	14	39	19	48	22	54	26	55	28	55
95	10	35	18	35	11	40	14	40	15	44	16	48
96	5	24	6	25	8	27	10	28	13	30	11	31
97	4	15	4	18	4	19	6	18	8	19	7	23
98	3	11	3	12	2	13	4	15	7	15	7	20
99	2	10	1	10	1	11	2	10	6	13	4	15
100	3	9	2	9	2	11	3	11	4	11	4	12
101	1	7	2	8	1	10	2	10	3	10	3	11
102	1	8	3	9	2	8	3	9	4	11	4	9

Enlargements of Bores—Continued.

Distance from Muzzle.	624TH FIRE.		674TH FIRE.		724TH FIRE.		774TH FIRE.		824TH FIRE.		888TH FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
10 in.	3	3	3	3	2	3	3	4	2	3	4	4
20	2	4	3	5	3	5	3	5	2	5	3	5
30	5	5	4	5	3	4	4	4	5	4	4	4
40	5	7	4	7	4	6	4	6	3	5	4	8
50	4	7	4	5	3	7	4	6	3	6	5	6
60	3	6	4	8	2	5	2	6	3	7	3	8
70	4	8	5	8	4	9	3	9	4	10	4	9
80	2	7	3	10	1	8	1	9	1	8	2	9
81	2	9	2	10	1	8	1	10	1	8	2	10
82	2	9	2	11	1	10	1	13	1	10	2	12
83	2	9	1	11	1	11	1	13	1	12	2	13
84	3	11	2	15	2	17	2	19	2	18	2	13
85	4	13	3	17	3	18	3	22	4	22	5	15
86	3	14	3	14	3	12	3	18	3	19	4	17
87	3	13	3	11	3	10	4	14	3	16	4	20
88	3	17	4	19	4	15	4	20	4	20	5	27
89	8	23	7	23	7	23	6	24	7	24	8	26
90	9	25	8	24	8	26	8	27	8	24	9	27
91	8	27	8	27	9	28	8	32	10	34	9	36
92	23	42	24	39	32	70	26	61	32	60	33	73
93	42	73	42	74	49	66	43	86	53	76	53	78
94	40	63	33	62	38	66	37	76	40	75	44	80
95	19	48	17	53	25	52	23	56	27	65	26	61
96	13	32	13	34	14	34	13	37	17	42	18	41
97	8	21	9	27	9	22	8	25	10	27	10	27
98	7	17	7	20	6	20	8	16	9	22	9	23
99	6	13	7	15	5	19	7	15	8	20	8	20
100	6	11	5	11	5	13	4	14	5	14	6	14
101	4	10	4	10	3	10	4	11	4	11	5	12
102	6	9	5	11	4	10	4	11	6	10	7	12

Enlargements of Bores—Continued.

Distance from Muzzle.	947TH FIRE.		1008TH FIRE.		1058TH FIRE.		1103RD FIRE.		1143RD FIRE.		1198TH FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
10 in.	4	4	4	4	2	4	3	3	3	4	3	4
20	4	7	4	5	2	5	3	5	2	4	3	5
30	5	6	6	4	4	4	5	4	5	5	4	4
40	4	7	5	6	4	5	5	6	3	7	3	6
50	4	7	5	6	4	6	4	6	3	7	3	6
60	3	10	4	6	4	6	4	7	3	7	2	6
70	6	10	4	10	4	9	3	8	3	7	2	7
80	3	11	5	9	3	8	3	6	3	8	1	8
81	2	12	4	9	2	9	2	9	1	7	1	8
82	2	14	3	14	2	10	2	10	1	13	1	11
83	2	14	2	13	2	10	2	11	1	13	0	11
84	3	20	3	19	2	14	2	14	2	17	1	12
85	4	23	4	21	3	16	4	14	3	20	3	14
86	3	18	4	19	2	14	2	14	2	14	2	15
87	4	19	4	18	3	15	3	18	3	17	2	20
88	7	27	5	24	4	24	3	24	5	25	3	25
89	9	27	9	26	9	25	6	23	8	27	6	24
90	10	27	9	27	10	25	7	24	8	27	7	24
91	11	34	11	31	12	36	12	40	9	64	12	54
92	39	84	48	104	51	94	58	99	50	77	42	97
93	58	105	64	124	67	92	73	120	70	80	60	103
94	44	96	50	82	58	92	54	88	48	80	45	89
95	30	61	30	63	32	62	54	59	30	78	23	67
96	20	44	23	53	21	45	24	41	21	45	15	46
97	12	25	13	26	11	39	13	35	13	32	11	27
98	12	24	11	23	9	20	9	22	10	29	11	21
99	9	21	11	23	8	19	8	21	8	19	9	20
100	8	13	10	15	6	15	6	17	7	14	8	14
101	6	13	6	11	5	11	6	11	6	11	7	12
102	6	14	6	11	6	10	7	11	8	14	6	13

Enlargements of Bores—Continued.

Distance from Muzzle.	1250TH FIRE.		1300TH FIRE.		1350TH FIRE.		1396TH FIRE.		1484TH FIRE.		1484TH FIRE, Horizontal.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
½ in.	3	75	3	75	3	76	—	75	4	75	3	38
10	2	5	3	5	2	4	4	7	5	4	5	4
20	2	5	3	5	1	4	2	6	3	4	4	5
30	3	5	3	5	3	4	3	6	2	5	5	5
40	3	7	5	7	3	4	2	7	1	7	4	8
50	4	7	2	8	3	5	2	5	2	6	3	6
60	2	7	2	8	2	5	2	6	3	8	3	7
70	2	6	2	8	2	9	3	12	3	6	5	13
80	1	9	1	8	0	7	0	13	1	10	3	14
81	2	8	1	9	0	8	0	11	0	10	2	15
82	1	12	1	14	0	11	1	14	0	13	1	14
83	1	13	1	15	0	15	1	14	0	13	2	17
84	2	17	1	18	0	15	1	17	1	16	2	17
85	4	20	3	20	2	21	2	21	3	21	2	14
86	3	17	2	16	1	17	2	18	2	19	2	17
87	3	18	2	16	1	16	2	17	2	22	3	17
88	4	23	4	21	3	23	3	23	2	28	3	21
89	7	27	7	27	6	26	8	29	8	30	5	30
90	8	27	8	30	8	30	9	31	9	33	8	30
91	11	64	4	70	10	78	10	114	19	200	7	27
92	52	73	48	180	53	138	65	223	113	225	11	40
93	67	110	74	125	71	142	76	195	83	200	30	50
94	52	95	51	100	48	107	51	104	68	124	27	44
95	27	80	39	74	28	73	29	77	37	79	8	34
96	19	50	19	47	15	67	22	57	23	54	6	30
97	12	30	13	30	8	31	13	27	10	34	6	25
98	10	26	11	30	7	25	13	30	12	29	3 ·	23
99	9	24	13	27	10	25	12	24	12	28	0	17
100	7	15	8	15	6	19	9	20	8	20	1	17
101	7	12	7	21	5	11	7	15	6	33	1	14
102	8	12	8	14	8	14	8	13	8	17	2	13

Enlargements of Bores—Continued.

Distance from Muzzle.	1573rd FIRE.		1628th FIRE.		1680th FIRE.		1780th FIRE.		1823rd FIRE.		1955th FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
½ in.	3	70	2	65	4	76	4	68	5	82	4	75
10	4	6	2	3	4	7	4	8	3	8	3	10
20	1	6	2	5	3	8	3	8	2	9	4	9
30	3	3	4	4	7	8	5	6	4	8	5	8
40	—1	5	4	6	5	7	4	9	3	10	4	10
50	—1	4	4	3	4	8	3	8	3	10	4	7
60	—1	5	2	4	4	7	7	8	2	10	4	10
70	—1	10	1	9	3	10	6	12	3	11	4	11
80	—1	7	2	8	2	10	4	10	1	10	1	13
81	0	4	2	9	2	9	3	9	1	10	2	12
82	0	4	1	7	2	13	3	12	1	11	2	12
83	—1	8	0	10	2	10	2	12	1	14	2	14
84	—2	13	0	10	4	13	2	15	1	14	2	17
85	0	18	2	13	3	15	3	20	3	17	4	19
86	—1	15	1	15	3	16	2	18	3	18	4	17
87	—1	18	1	18	3	18	2	17	2	21	4	18
88	—1	23	3	20	4	22	3	29	4	30	5	28
89	—1	23	6	27	9	29	9	32	7	35	10	33
90	2	29	8	27	10	29	8	32	8	180	10	180
91	8	76	13	44	13	184	85	275	23	320	21	—
92	47	145	54	157	47	141	81	285	104	320	84	—
93	69	150	81	128	85	166	92	173	102	320	111	—
94	50	124	54	104	57	108	61	117	65	143	67	156
95	23	80	33	90	33	93	36	91	40	97	44	86
96	10	52	24	57	22	61	24	60	27	55	29	50
97	5	30	16	43	14	43	14	44	13	63	13	59
98	5	28	14	30	14	31	14	30	12	28	14	38
99	7	21	14	26	14	25	12	27	12	47	12	30
100	7	16	7	19	11	17	9	20	7	19	10	33
101	2	19	6	14	7	15	8	25	5	17	4	15
102	0	14	11	15	13	15	11	22	8	18	8	18

Enlargements of Bores—Continued.

Distance from Muzzle.	2023rd FIRE.		2023rd FIRE, Horizontal.		2093rd FIRE.		2163rd FIRE.		2224th FIRE.		2265th FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
½ in.	4	77	—	—	3	81	—1	81	2	74	—2	74
10	2	6	—	—	0	2	—2	1	1	5	—1	5
20	2	6	—	—	—2	2	—1	3	0	4	—2	4
30	2	5	—	—	—1	3	—1	2	4	5	—1	4
40	4	8	—	—	—1	4	—1	6	2	7	—1	7
50	3	5	—	—	—1	3	—1	2	1	6	—1	5
60	2	7	—	—	—1	4	—2	3	1	6	—1	5
70	5	10	—	—	0	8	—2	8	1	8	—3	9
80	2	10	—	—	—5	5	—2	6	0	8	—1	10
81	1	8	—	—	—3	5	—2	7	0	8	—1	9
82	1	9	—	—	—2	11	—2	8	0	10	—1	10
83	1	10	—	—	—2	14	—3	8	0	14	—3	10
84	2	13	—	—	—1	15	—2	10	1	17	—3	12
85	3	15	—	—	0	19	—3	10	2	18	—3	16
86	2	15	—	—	—1	16	—4	10	1	16	—2	15
87	3	17	4	20	—1	23	—1	9	2	22	—1	19
88	4	28	4	22	0	27	—1	22	3	29	—1	28
89	8	28	7	34	5	31	2	29	9	33	3	33
90	10	300	10	34	8	320	2	27	10	138	7	70
91	19	—	12	30	16	—	23	—	30	—	30	—
92	78	—	20	35	62	—	87	—	116	—	80	—
93	95	—	46	63	89	—	100	—	111	—	102	—
94	69	170	27	53	64	131	77	155	70	135	66	320
95	38	76	14	33	38	98	49	93	52	88	47	118
96	25	55	10	31	24	59	24	63	29	64	24	49
97	16	34	6	22	13	33	14	37	15	44	14	32
98	14	39	5	22	10	33	10	27	14	34	13	22
99	14	29	3	22	10	24	11	24	12	23	9	21
100	10	29	4	14	9	17	7	30	10	20	8	17
101	8	15	3	15	6	12	2	13	10	13	4	11
102	10	15	1	11	8	11	8	15	8	17	6	15

Enlargements of Bores—Continued.

Distance from Muzzle.	2300TH FIRE.		2370TH FIRE.		2450TH FIRE.		2450TH FIRE, Horizontal.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
$\frac{1}{2}$ in.	5	75	3	75	5	75	3	32
10	3	5	3	5	3	5	2	3
20	4	7	3	7	1	5	3	4
30	5	5	5	6	3	6	4	4
40	5	7	3	9	3	7	4	7
50	4	8	3	8	2	7	3	5
60	3	8	3	8	2	9	2	6
70	3	9	0	10	2	10	4	10
80	2	8	1	9	1	12	3	10
81	2	8	0	11	1	11	2	11
82	2	12	0	15	0	13	1	11
83	2	12	0	14	0	15	1	12
84	3	13	1	20	1	18	1	15
85	4	15	3	24	2	18	2	13
86	3	14	2	18	2	17	2	13
87	4	22	2	23	2	25	2	15
88	6	27	3	30	4	34	2	20
89	9	32	9	31	8	38	8	38
90	11	178	11	—	11	57	11	46
91	167	—	40	—	40	—	13	31
92	98	—	116	—	109	—	30	47
93	108	—	118	—	119	—	58	77
94	73	—	74	—	86	150	40	58
95	49	115	43	100	50	90	18	42
96	30	57	28	63	30	60	11	50
97	17	33	19	47	14	60	7	32
98	14	19	14	24	15	33	4	24
99	13	24	13	24	10	30	2	21
100	11	20	11	15	10	23	3	20
101	10	13	6	19	7	19	2	13
102	10	15	11	23	12	20	1	13

TABLE *showing the diameters of Vents, after the undermentioned numbers of fires, in hundredths of an inch.*

TABLE OF DIAMETERS OF THE 1ST VENT.

Distance from Exterior.	474TH FIRE.		524TH FIRE.		574TH FIRE.		624TH FIRE.		674TH FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
1 inch,	.25	.23	.26	.24	.27	.25	.30	.27	.32	.31
2	.25	.22	.26	.24	.28	.28	.31	.27	.33	.30
3	.26	.24	.28	.26	.30	.27	.31	.29	.33	.31
4	.27	.25	.28	.25	.31	.28	.32	.29	.34	.31
5	.26	.26	.30	.26	.32	.29	.33	.31	.37	.33
6	.31	.26	.30	.26	.31	.29	.34	.32	.35	.32
7	.29	·27	.31	.29	.32	.31	.34	.32	.35	.33
8	.26	.28	.35	.30	.35	.31	.40	.33	.43	.34
9	.30	.30	.36	.32	.38	.33	.52	.34	.41	.38
10	.34	.32	.35	.36	.38	.38	.40	.40	.70	.42
11	.34	.36	.39	.32	.40	.34	.34	.39	.70	.41

TABLE OF DIAMETERS OF THE 2ND VENT.

Distance from Exterior.	368TH FIRE.		431ST FIRE.		471ST FIRE.		526TH FIRE.		578TH FIRE.		676TH FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow	Solid.	Hollow.	Solid.
1 inch,	.21	.20	.22	.21	.22	.22	.26	.24	.28	.25	.30	.25
2	.21	.20	.23	.22	.24	.24	.26	.25	.30	25	.32	.26
3	.22	.21	.24	.22	.25	.24	.27	.25	.31	2 5	.32	.26
4	.23	.21	.25	.23	.25	.24	.27	.25	.31	.27	.32	.28
5	.24	.22	.26	.24	.29	.25	.31	.27	.32	.30	.33	.30
6	.24	.23	.26	.24	.30	.26	.31	.30	.31	.30	.33	.31
7	.25	.23	.26	.24	.30	.27	.33	.30	.31	.32	.36	.33
8	.26	.24	.28	.25	.27	.28	.31	.30	.36	.34	.34	.35
9	.30	.25	.31	.26	.29	.29	.30	.31	.40	.38	.42	.40
10	.31	.26	.35	.30	.34	.31	.36	.33	.35	.43	.42	.50
11	.28	.23	.38	.24	.31	.26	.38	.32	.45	.60	.42	.42

TABLE OF DIAMETERS OF THE 3RD VENT.

Distance from Exterior.	605TH FIRE.		743RD FIRE.		813TH FIRE.		874TH FIRE.	
	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.
1 inch,	.22	.22	.25	.25	.27	.26	.30	.29
2	.22	.22	.26	.26	.30	.28	.32	.30
3	.23	.23	.28	.27	.31	.27	.33	.30
4	.26	.24	.29	.26	.32	.27	.36	.29
5	.26	.24	.30	.28	.32	.27	.34	.31
6	.27	.28	.30	.31	.33	.30	.35	.35
7	.23	.23	.32	.31	.36	.33	.39	.35
8	.29	.32	.32	.33	.32	.34	.34	.36
9	.34	.26	.36	.34	.40	.32	.42	.46
10	.26	.26	.26	.27	.30	.29	.32	.31
11	.20	.26	.20	.24	.20	.25	.31	.26

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Meteorological Observations in October, 1858.

Working Days	TEMPERATURE		WINDS				WEATHER
	Thermometer. Mean.	Hygrometer. Mean.	At 7 A.M. Direction.	Force.	At 2 P.M. Direction.	Force.	
1	61.66	59.66	S. W.	3	N. W.	3	Cloudy, showery, and thunder.
2	55.33	52.33	W.	1	W.	1	Changeable.
4	71.	65.33	S. W.	2	W.	3	Changeable.
5	61.66	57.	N. E.	2	W.	2	Fair.
6	60.33	54.66	N. E.	1	N.	1	Cloudy.
7	56.	51.66	S. W.	2	W.	4	Changeable.
8	65.66	40.33	W.	3	S. W.	2	Fair.
9	48.66	42.66	S. W.	3	S. W.	3	Fair.
11	52.66	52.33	S. W.	1	N.	1	Cloudy, and light frost.
12	58.33	56.33	N. E.	1	S.	2	Cloudy, and light frost.
13	58.33	55.33	S. E.	1	S.	3	Cloudy, rainy, and wind.
14	51.33	46.66	S. W.	3	S. W.	4	Fair.
15	47.33	44.	S. W.	0	S. W.	2	Changeable, light frost.
16	52.66	47.66	S. E.	1	S. E.	2	Changeable, light frost.
18	54.66	54.	N. E.	2	S. W.	1	Changeable, light frost.
19	57.	56.33	S. E.	1	S. W.	1	Fair, light frost.
20	60.66	56.33	N. E.	1	S.	2	Changeable.
21	62.	59.	E.	1	S. E.	1	Cloudy, with light showers.
22	58.33	56.66	S.	0	S. W.	0	Cloudy, with light showers.
23	52.66	49.	S. W.	0	N.	2	Changeable.
25	49.66	44.66	N.	2	N. E.	2	Fair, with light frost.
26	49.33	45.	N. E.	1	S.	1	Changeable.
27	47.33	43.	N. E.	1	S.	2	Cloudy.
28	53.33	49.	N. E.	1	S. E.	1	Cloudy.
29	55.33	52.33	N. E.	0	S. E.	1	Cloudy, and light rain.
30	54.66	52 33	N. E.	0	N. W.	2	Cloudy, and light rain.

Meteorological Observations in November, 1858.

Working Days	TEMPERATURE		WINDS				WEATHER
	THERMOMETER.	HYGROMETER.	AT 7 A.M.		AT 2 P.M.		
	Mean.	Mean.	Direction.	Force.	Direction.	Force.	
1	51.66	47.66	N. E.	0	N. E.	1	Cloudy.
2	56.33	51.66	N. E.	2	E.	2	Cloudy, and rain.
3	54.66	50.66	N. E.	0	S.	1	Cloudy.
4	51.66	48.	N. E.	0	S. W.	2	Cloudy.
5	48.	46.	W.	1	N.	2	Cloudy.
6	45.	42.	N. W.	2	S. W.	3	Cloudy, and rain.
8	42.	43.33	S. W.	2	S. W.	3	Fair.
9	41.	38.66	S. W.	1	N. W.	2	Cloudy.
10	41.33	38.66	S. W.	1	S. W.	1	Cloudy.
11	40.33	37.66	S. W.	0	E.	1	Fair.
12	42.33	40.	N.	0	S.	2	Fair.
13	38.	35.	S.	2	W.	2	Cloudy, and rain.
15	33.66	29.66	S. W.	1	N.	3	Cloudy, and snow.
16	31.33	30.33	S. W.	3	S. W.	4	Cloudy, and snow.
17	33.33	32.	S. W.	0	S. W.	2	Cloudy.
18	34.66	32.	S. W.	3	W.	3	Cloudy, and snow.
19	29.66	28.66	S. W.	2	W.	3	Cloudy, and frost.
20	28.	26.66	N. E.	1	N. E.	1	Cloudy, and frost.
22	36.66	31.66	N. E.	1	N. E.	1	Cloudy, and heavy rain.
23	36.33	34.33	W.	3	S. W.	3	Cloudy, and snow.
24	36.66	34.	S. W.	2	S. W.	2	Changeable.
25	34.33	32.33	W.	2	W.	1	Changeable.
26	33.66	31.33	W.	1	S. W.	3	Cloudy, with snow.
27	33.66	31.33	N.	1	E.	1	Cloudy, heavy snow.
29	34.33	32.	S. W.	4	W.	1	Cloudy.
30	30.66	29.33			S. W.	3	Cloudy.

Meteorological Observations in December, 1858.

Working Days.	TEMPERATURE.		WINDS.				WEATHER.
	THERMOMETER. Mean.	HYGROMETER. Mean.	At 7 A.M. Direction.	Force.	At 2 P.M. Direction.	Force.	
1	29.33	27.	N.	1	N. E.	1	Fair.
2	39.	37.33	N.	0	S. W.	2	Cloudy, with rain.
3	46.66	29.	N. E.	1	S. W.	2	Changeable.
4	52.66	51.33	N.	0	S.	1	Changeable.
6	38.	34.66	S. W.	1	N. E.	0	Fair, fine day.
7	49.	44.66	N. E.	1	N. E.	0	Cloudy, with light rain.
8	34.	27.	S. W.	1	N. E.	3	Fair.
9	19.	18.33	S. W.	3	S.	2	Cloudy, with snow.
10	26.66	25.66	S. W.	0	S.	2	Fair, light frost.
11	31.33	29.66	E.	0	S. W.	2	Cloudy.
13	47.66	46.66	N. W.	0	S.	0	Cloudy, with heavy rain.
14	52.33	50.	S. E.	0	E.	1	Cloudy, with heavy rain.
15	47.33	43.33	S. E.	2	S. W.	2	Cloudy, rain, and heavy wind.
16	37.33	34.	S.	0	S. W.	3	Fair.
17	35.66	32.33	S.	1	S. W.	2	Fair and pleasant.
18	32.33	26.26	N.	1	N. E.	2	Cloudy.
20	43.33	41.33	S. E.	1	N. E.	1	Changeable.
21	45.66	43.66	N. W.	1	S. W.	2	Cloudy, with rain.
22	37.66	35.	S. W.	4	S.	3	Fair.
23	39.66	36.33	S. E.	1	S. W.	3	Changeable.
24	29.66	27.66	S. W.	3	N. W.	2	Cloudy.
25	23.66	25.66	N.	0	N. E.	1	Fair.
27	40.33	37.66	S. W.	1	S. W.	0	Cloudy.
28	35.33	33.	N. W.	0	N. W.	0	Fair.
29	37.33	36.	N. W.	2	N. W.	0	Changeable.
30	38.33	36.	N.	1	N. E.	1	Changeable.
31	44.	41.66	S. E.	1	S. W.	0	Rain all day.

The enlargement of the bore from actual stretching of the metal, is the best indication we have of the approaching rupture of a gun; enlargement from this cause being the permanent set due to the strain to which the metal has been subjected. In guns that have been fired any considerable number of times, a very small proportion of the greatest enlargement is due to this cause.

The greatest enlargement is mainly due to the cutting effects of the gas in passing through the windage space, before the shot has sensibly moved from its seat. These effects are greatest over the top of the shot, where the windage is greatest.

The horizontal diameter at the seat of the charge is less affected by the gas than any other, at which the bore is subjected to the maximum pressure.

The enlargement of this diameter is therefore the best indication of the deterioration of the gun.

The greatest enlargement which the Star Gauge would measure, was .320; the enlargement of the solid cast gun was greater than this at 93 inches from the muzzle at the 1573d fire, and was beyond it at the 2450th fire, from 89 inches to 94 inches. The greatest enlargement of this gun cannot be much, if any, less than .500 in.; while the greatest that could be found in the hollow gun was .260, and that in but one point.

Endurance.

The guns of 1858 have both been fired 2450 rounds, exclusive of the proof charges.

The cascabel dropped off the solid cast gun at the 761st fire, and a number of cracks were discovered in the face of the muzzle after the 1209th fire, some extending back three or four inches. These cracks have not since increased, and are believed to be due to some accidental cause, rather than to the regular deterioration of the gun from firing.

The cascabel dropped off the hollow cast gun at the 1379th fire. All the trunnions of both guns are slightly cracked at the junctions of the guns and rim bases, the left trunnion of the hollow gun apparently the worst.

There is a very marked difference in the interior appearance of the two guns, the bore of the solid cast gun being greatly more deteriorated than that of the hollow cast gun.

There are three cracks radiating from the interior of the first, and one from

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that of the second vent, in the solid gun.   Those from the first vent are from 2 to 3 inches long, while that from the second vent is between 3 and 4 inches long, running in an almost transverse direction around towards the first vent.

There are no cracks perceptible in the hollow gun.

These guns have each been pierced with four vents.   The vents, as they became too large for use, say .4 in. or .5 in., were filled with zinc, and new ones bored ; new vents being bored in both guns after the same number of fires.

The positions of the vents were all lateral, or not in planes containing the axes of the guns.

The first vents were 6 inches on the exterior and 3 inches on the interior, to the left of planes containing the axes of the guns, and perpendicular to those of the trunnions, and were in planes perpendicular to the axes of the guns at 3 inches from the bottoms of the bores.

The second vents occupied similar positions on the right sides of the guns.

The third vents were 12 inches on the exterior to the left of the first, and passed, in direction, the same distance from the axes of the guns, and were 3 inches further forward.

The fourth vents occupied similar positions on the right sides of the guns. (See Plate 6.)

Comparison of Solid Guns of 1857.

DATA FOR COMPARISON.	West Point.	Fort Pitt.
Endurance, ...	168 rounds.	398 rounds.
Tenacity for head specimens, ...	30616 lbs.	24648 lbs.
Tenacity of exterior gun specimens, ...	26000 "	21000 "
Tenacity of interior gun specimens, ...	24000 "	19000 "
Density of head specimens, ...	7.235	7.142
Density of gun specimens, ...	7.242	7.130
Extensibility, per linear inch, of interior specimens, . .	.0023628	.0028257
Ultimate linear set of interior specimens, ...	.0008457	.0014114
Ultimate linear set of exterior specimens, ...	.0010843	.0016000
Extensibility of exterior specimens, ...	.0032186	.0033657
Ultimate restoration of interior specimens, ...	.0015171	.0014143
Ultimate restoration of exterior specimens, ...	.0015194	.0013000
Compressibility, at 3000 lbs., of interior specimens, . .	.0022500	.0034900
Compressibility, at 3000 lbs., of exterior specimens, . .	.0023800	.0034100
Restoration, per linear inch, of interior specimens, . . .	.0015600	.0017200
Restoration, per lineal inch, of exterior specimens, . . .	.0015600	.0015200
Ultimate set of interior specimens, ...	.000690	.001770
Ultimate set of exterior specimens, ...	.000820	.001890
Enlargement of chamber at interior rupture, 88th fire, . .	.005	.011

PLATE VI
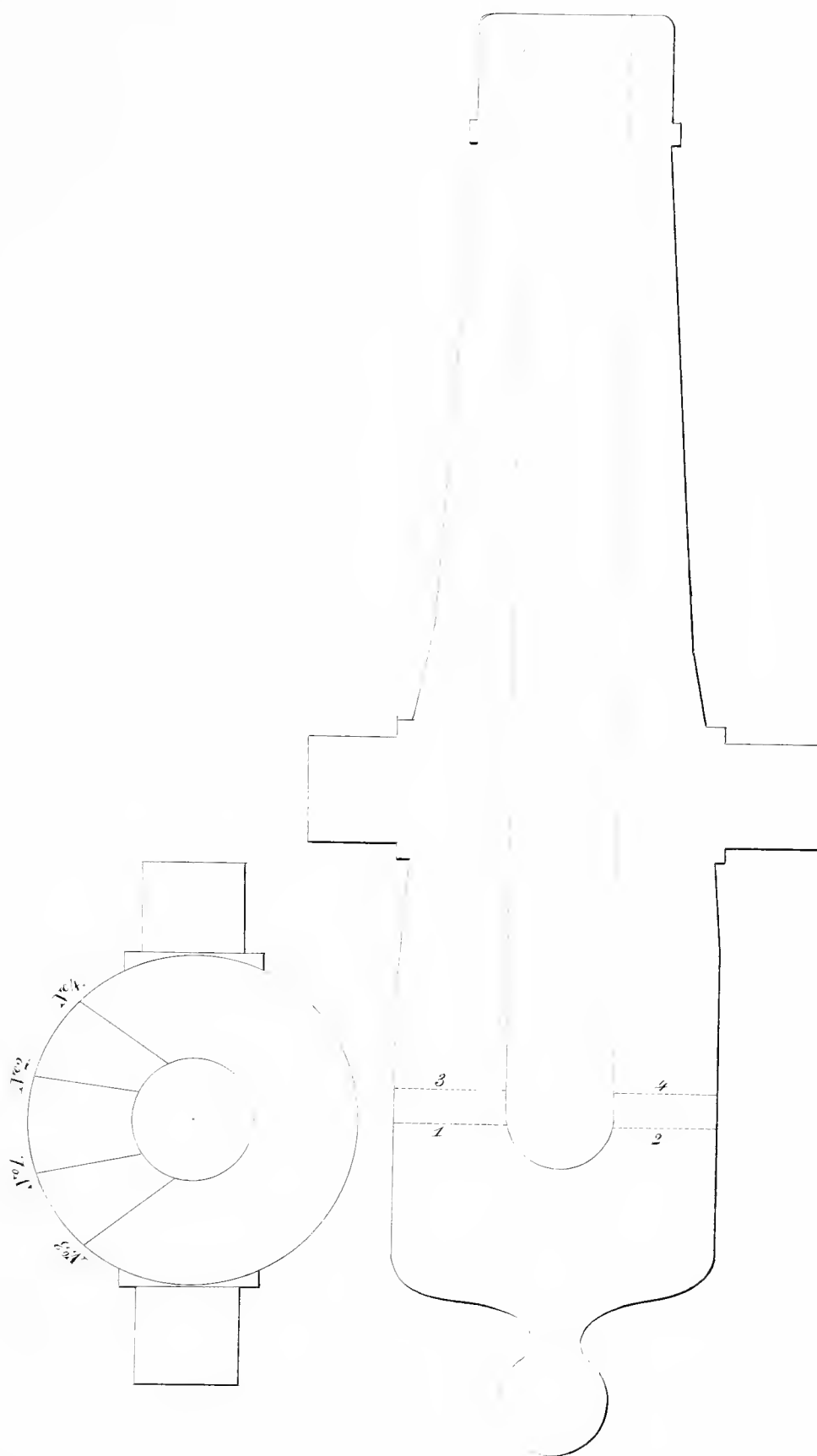
For the above data, see foregoing tables at pages 80 to 88, inclusive.

The above data show the metal in the West Point gun to be more dense, of much greater strength, more elastic, and much more incompressible than that in the Fort Pitt gun, and of almost equal ultimate extensibility; or that it is superior in every quality except one, and but slightly inferior in that. Yet the endurance of the Fort Pitt gun was more than double that of the West Point gun. In other words, the *inferior* metal makes the *superior solid* cast gun.

Startlingly absurd as this conclusion appears, it is nevertheless true, and admits of satisfactory explanation, in strict accordance with the known properties of cast iron.

The iron of which these guns were made was identical, in quality, when it went into the melting furnaces. The difference in quality, as found in the guns, was caused by the difference in treatment which it received in the furnaces, and by the different rates of cooling to which the guns were subjected after casting. The Fort Pitt furnaces have a stronger draft, melt quicker, and " work lower," or decarbonize their iron less, than the West Point furnaces.

The West Point gun mould was rammed up in green or moist sand to a point above the trunnions, that part of the mould containing the chase of the gun being entirely uncovered.

The Fort Pitt gun mould was placed in a closely covered pit, which had been previously heated by fire, and in which a moderate fire was burning at the time of casting, and continued to burn for some time after.

Green or moist sand is a very good conductor of heat, owing to the evaporation of the moisture which it contains. It is well known that a body will cool much more rapidly in the open air than in a closely covered pit, even without any application of heat from other sources.

There can be no doubt, therefore, that the West Point gun cooled more rapidly than the Fort Pitt gun, nor that it was composed of higher or more decarbonized iron. Now it is well known that the higher the iron, and the more rapidly it is cooled, the greater will be its contraction in cooling.

It is equally well known that the greater the contraction of the iron, the more liable is the casting to be strained in cooling; and in no case is this danger more imminent, or the strain produced more certain to be injurious, than in cooling, from the exterior, guns, hydraulic cylinders, &c., of large diameter. For (for the reasons given in my letter to Colonel Craig, hereto

appended, page 93,) the strain due to contraction in cooling is sure, in these cases, to act in concert with the bursting force.

There can be no doubt, therefore, that the superior qualities which the *iron* in the West Point gun has been shown to possess, were more than neutralized *in the gun* by the greater strain to which it was subjected in cooling; but additional support of this conclusion is found in the less enlargement of the chamber of the West Point than that of the Fort Pitt gun, when first discovered to be cracked, in proportion to the ultimate permanent set which the iron would undergo from a state of perfect freedom from strain.

The ultimate set per inch in length of the interior specimen of the West Point gun (as per table of data) is $= .0008457$ in.; which, multiplied by 8 in., the diameter of the chamber, gives .0067656 in. as the enlargement which the chamber should undergo at interior rupture, or at the first appearance of cracks in the chamber, from the permanent set of the metal alone. Now, if we attribute the total enlargement of the chambers at the 88th fire to this cause, we can account for only .0050000 in., leaving for the permanent set which 8 in. in length of this iron had taken from the strain to which it had been subjected in cooling $= .0017656$ in.; this sum divided by 8 gives .0002257 for the permanent set per inch in length due to the strain from contraction in cooling.

Reference to the table of extension, &c., of interior specimen from West Point gun (page 81), will show that about 18000 lbs. per square inch were required to produce this amount of permanent set in this iron.

The ultimate strength per square inch of the interior specimen from this gun was 24000 lbs.; we consequently conclude that the interior portions of this gun had been subjected, by contraction in cooling, to a strain equal to about *three-fourths* of its ultimate strength.

Similar reasoning from similar data, obtained from the Fort Pitt gun, shows the strain to which its interior portions had been subjected, by cooling, to be between 6000 and 7000 lbs. per square inch. The ultimate strength of the interior specimen from this gun was 19000 lbs.; thus showing the interior portions of this gun to have been subjected, by contraction in cooling, to a strain equal to about *one-third* of its ultimate strength.

With these facts before us, we should be no longer astonished at the result of the *powder proof* of these guns.

Comparison of the Fort Pitt Guns of 1857.

The hollow cast gun of this pair being still unbroken, the properties of the metal around the seat of the charge in this gun have not been ascertained.

The only data for comparison of these guns are the Tenacity and Density of their head specimens, which are as follows, viz :—

	Hollow cast Gun.	Solid cast Gun.
Tenacity, ...	26082 lbs.	24648 lbs.
Density, ...	7.172	7.137

The hollow cast gun being superior in both these qualities.

The hollow cast gun has been fired 1600 rounds, and is still unbroken, while the solid cast gun burst at the 399th fire, both including proof charges.

The iron of which these guns were made entered the gun moulds identical in quality, the moulds being simultaneously filled from the same pool of melted iron.

The guns were fired till that cast solid burst, alternate rounds, with equal charges of the same quality of powder, and one solid shot and sabot.

The difference in their endurance can therefore be attributed to no other cause than the difference in mode of cooling to which they were subjected after casting.

Comparison of the Fort Pitt Guns of 1857 *and* 1858.

Only one (the solid cast gun of 1857) of these guns being broken, the only data for comparison are the Tenacity and Density of the head specimens, which are as follows, viz :—

	Hollow Guns.	Solid Guns.
Tenacity of guns of 1857, . . .	26082	24454
Tenacity of guns of 1858, . . .	27733	26038
Density of guns of 1857, . . .	7.172	7.142
Density of guns of 1858, . . .	7.201	7.159

These data show both guns of 1858 to be superior, in both density and

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tenacity, to those of 1857, the difference being more strongly marked in the hollow than in the solid cast guns; they likewise show the hollow cast gun, of both pairs, to be superior, in both these qualities, to the solid gun cast at the same time.

The only assignable cause of difference in quality of the iron of these two pairs of guns, is that the furnaces, at the time of casting the guns of 1857, were in almost daily use, and the bodies and chimneys were warm, giving a stronger draft at the time of lighting than was obtained in melting the iron for the guns of 1858; for these guns were the first heat, of any magnitude, that was melted in these furnaces after the burning of the Fort Pitt Works.

The furnaces were consequently colder in both bodies and chimneys, gave a more sluggish draft, and required a longer time to melt, and consequently decarbonized their iron more for the guns of 1858 than for those of 1857. This further decarbonization improved the quality of this iron. The iron for the two pairs of guns was the same length of time in fusion.

The difference in quality of the iron, in the solid and hollow gun, of both pairs, is believed to be due to the more rapid rate of cooling to which the hollow guns were subjected; for this difference has been found to exist in every pair that has been made of iron sufficiently low to be improved by a more rapid rate of cooling than that to which it was subjected in the solid gun.

It is well known that every variety of cast iron has a maximum of strength, elasticity, and extensibility, taken as a whole, or as constituting its *capacity* for *work*, which is due to a certain degree of decarbonization, and a certain rate of cooling.

If the decarbonization and rate of cooling be carried beyond this, the iron may have its tenacity and elasticity increased, but its extensibility will be diminished in a greater ratio. If the degree of decarbonization and rate of cooling, or either, be under this, the extensibility will be increased, but the tenacity and elasticity will be diminished in a greater ratio.

The iron of which the guns of 1857 and 1858 were made was far below its maximum *capacity* for *work*, being susceptible of being brought up to a tenacity of 35000 lbs. per square inch, at least, without sensibly impairing its extensibility, and with an increase of elasticity; yet we find a tenacity of 19000 lbs. to give a solid cast gun of more than double the endurance of that having a tenacity of 24000 lbs. (See specimens for extension, pp. 80 to 88, inclusive.)

It hence appears that the solid mode of casting guns enables us to avail ourselves of only about one-half the strength, or capacity for work, of which our material is susceptible.

The hollow mode, it is believed, enables us to avail ourselves of the best material, brought up to its best capacity for work, by preserving it from the injurious strains to which it is subjected, in cooling, by the solid mode.

Witness the pair of 8-inch guns of 1851, with a tenacity of 38000 lbs.: the solid gun burst at the 73d fire, while the hollow gun has been fired 1500 rounds, and is unbroken.

The hollow cast gun of 1858 has been fired 2452 rounds, and that of 1857 1600 rounds; yet the gun of 1857 is apparently more deteriorated than that of 1858. The solid cast gun of 1858 has likewise been fired 2452 rounds, while that of 1857 burst at the 399th fire, all including proof charges.

These last named guns were all fired with the same weight of both powder and shot; and it has already been shown that the powder used in the proof of the guns of 1857 differed but little, if any, in quality from that used in the proof of those of 1858.

The difference in quality of the metal in these two pairs of guns is not sufficient to account for the difference in their endurance; and as regards the solid cast guns, it would be difficult to say which gun the difference in quality of the metal favored. As regards the hollow guns, I have no doubt that the better metal makes the better gun.

What may be the ultimate difference in the endurance of the two hollow cast guns cannot be foreseen, as neither gun is yet broken.

The difference in endurance of the two solid cast guns, though not yet fully developed, is of sufficient magnitude to require the action of a very efficient cause to produce it.

The guns of 1857 were of the old Columbiad model, modified to the extent of the removal of the base ring; while those of 1858 were of a new model, without chambers or ratchets in the breech, and with increased thickness of metal in the breech, being over $1\frac{1}{2}$ calibres thick in that part. (See Plate 6.)

These guns are modelled at the breech, and around the seat of the charge, in close conformity to the theory on that subject, as given in my Report of Experiments made in 1856, and to the results of my experiments for determining the proper thickness of metal in the breech; and it is believed to be

mainly to the difference in model that the difference in endurance of these guns ought to be attributed.

There is no other *known* cause for any considerable difference, yet we cannot with certainty announce this as the only cause, for a single result is not conclusive; and differences, almost if not quite as great, in the endurance of solid cast guns, have been found to exist, without *any known* cause.

For example: 8-inch Columbiad No. 82, cast solid at the Fort Pitt foundry in 1846, has been fired 2582 times, and is unbroken; while No. 84 of the same series, cast two days after, of precisely the same quality of iron, and cooled in the same manner, burst at the 801st fire, with the same charges.

Another example is furnished by the West Point foundry.

A 10-inch gun, (No. 2,) cast at that foundry in 1845, was fired, at Fort Monroe Arsenal, by Major Ramsay, 500 rounds with 18 lbs. of powder, (400 rounds with shells, and 100 with solid shot,) then 8 rounds with 18 lbs. of powder and 2 solid shot for the first fire, 3 for the second, 4 for the third, &c., increasing by one solid shot at each fire up to 9 shot; then one round with 36 lbs. powder and 9 solid shot, *without rupture;* while gun No. 3, of the same series, fired at the same place by Capt. Dyer, endured as follows, viz. : —

70 rounds with 18 lbs. powder and 1 solid shot.
37　"　　"　18　"　　"　　"　1 shell.
83　"　　"　20　"　　"　　"　1 solid shot.
 5　"　　"　20　"　　"　　"　1 shell.

Total, 195 rounds—and gun burst.

TABLE *showing the mechanical tests, weight of charges, and endurance of all the guns cast up to this time, for the purpose of determining the relative merits of the solid and hollow modes of casting.*

When Cast and Proved.	Number of Gun.	Calibre.	Weight of Charges.		Density of Heads.		Tenacity of Heads.		Number of Times Fired.		REMARKS.
			Powder.	Shot.	Hollow.	Solid.	Hollow.	Solid.	Hollow.	Solid.	
1849	1	8 inch,	10 lbs.	64 lbs.	—	7.221	—	27014	—	85	Burst.
1849	2	8 "	10 "	64 "	7.226	—	27963	—	251	—	Burst.
1851	3	8 "	10 "	64 "	—	7.286	—	37984	—	73	Burst.
1851	4	8 "	10 "	64 "	7.286	—	37816	—	1500	—	Not broken.
1851	5	10 "	18 "	125 "	—	7.290	—	37129	—	20	Burst.
1851	6	10 "	18 "	125 "	7.294	—	38513	—	249	—	Burst.
1852	160	32 pds.	8 " 10¾ "	32 " 32 "	7.281 —	— 7.271	34307 —	— 33590	1000} 20	— 1000	Burst, with 16 lbs. of powder and 2 shot, at 1021st fire.
1852	161	32 "	8 " 10¾ "	32 " 32 "	—	—	—	—	—	6	Burst.
1856	331	10 inch,	18 "	125 "	7.215	—	31835	—	315	—	Burst.
1856	332	10 "	18 "	125 "	—	7.160	—	29770	—	26	Burst.
1857	334	10 "	14 "	125 "	7.172	—	26082	—	1600	—	Not broken.
1857	335	10 "	14 "	125 "	—	7.142	—	24454	—	399	Burst.
1857	983 W. P.	10 "	14 "	125 "	—	7.235	—	30616	—	169	Burst; W. Pt. gun.
1858	362	10 "	14 "	125 "	7.201	—	27733	—	2452	—	Not broken.
1858	363	10 "	14 "	125 "	—	7.159	—	26088	—	2452	Not broken.

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Those numbers or pairs of guns included in the same brackets in the above table were cast at the same time, and from the same pool of melted iron; one being cast solid and cooled from the exterior, and the other cast hollow and cooled from the interior.

The results recorded in the above table show the hollow cast gun in every pair (in which one or both guns have been broken) to be superior, in endurance, to the solid cast gun. The results may be grouped as follows, viz.:—Of the two pairs of 8-inch guns, the solid cast guns endured 158 rounds — both burst. Hollow cast guns endured 1751 rounds — one gun unbroken.

Of the two pairs of 10-inch guns, fired with 18 lbs. charges, those cast solid were fired 46 rounds — both burst. Those cast hollow were fired 564 rounds — both burst.

Of the two pairs of 10-inch guns, fired with 14 lbs. charges, those cast solid have been fired 2851 rounds — one gun unbroken. Those cast hollow have been fired 4052 rounds — neither gun broken !

Of the pair of 32-pounders, the hollow cast gun was superior, but the comparison was destroyed by double charging the hollow cast gun.

Of the three pairs of 10-inch, and two pairs of 8-inch guns, when one or both of each pair has been broken, those cast solid have been fired 603 rounds — guns all broke. Those cast hollow have been fired 3915 rounds, and two guns unbroken.

Out of the five 10-inch guns, made of the same iron (that selected at the West Point foundry), two good hollow cast guns have been made, one having been fired 1600 rounds, and the other 2452, and neither broken; while of the three solid cast guns two have burst, one at the 169th, and the other at the 399th fire; the other has been fired 2452 rounds — unbroken — and is the *only good solid cast gun* out of the seven experimental Columbiads cast in that manner.

It should likewise be borne in mind that these results have been obtained under the most unfavorable circumstances for the hollow made; the only experience in that mode of casting being that furnished in casting the experimental guns; while the solid mode has had the benefit of long experience, in both Europe and this country, and the iron used in casting the experimental guns has always been selected with a view to making the best *solid cast* gun possible.

The 32-pounders, and all but one of the 10-inch solid cast guns, have had the benefit, as far as it was possible to apply it, of the new mode of cooling, having been retarded in their rates of cooling by having fires burning in the pits while cooling, which is not the ordinary mode of cooling solid cast guns.

RECAPITULATION.

Casting.

Guns of 1857 and 1858, for testing merits of solid and hollow modes of cooling, were cast from the same iron, and under similar circumstances.

Mechanical Tests.

The hollow cast gun, in both pairs, was superior to that cast solid, in both tenacity and density.

Model of Guns.

The guns of 1857 were made with, and those of 1858 without chambers, with increased thickness of metal in the breech.

Proof.

The guns of 1857 and 1858 were proved in the same manner, and with the same charges of powder and shot.

Powder Used.

The powder used in the proof of the guns of 1857 differed but little in quality from that used in the proof of the guns of 1858.

Enlargement.

The guns of 1857 were enlarged more by the same number of rounds than those of 1858.

Deterioration.

The solid cast gun of 1858 appears to be greatly more deteriorated from firing than the hollow cast gun, cast at the same time.

Comparison of Solid Guns of 1857.

The metal in the West Point gun was superior in quality to that of the

Fort Pitt gun, yet the latter endured more than double as many rounds as the former.

Strain from Contraction in Cooling.

The West Point gun of 1857 was subjected, by contraction in cooling, to about three-fourths, and the Fort Pitt solid gun, of same year, to about one-third of its ultimate strength.

Working of Furnaces.

The fort Pitt Furnaces melt quicker, and "work lower," or decarbonize their iron less, than the West Point furnaces.

Comparison of Fort Pitt Guns of 1857.

The difference in endurance of these guns can be attributed to no other cause than the difference in their mode of cooling. Solid cast gun burst at 399th fire; hollow cast gun has been fired 1600 times, and is unbroken.

Comparison of Fort Pitt Guns of 1857 and 1858.

There is no other *known* cause for difference in endurance of these pairs of guns, than the difference in their model. Accidental or *unknown* causes have produced as great differences in endurance.

Iron for Guns.

Solid cast guns must be made of inferior iron to prevent fatal contraction in cooling; while the hollow method enables us to use the best quality of iron brought to its maximum capacity for work.

Endurance.

In the six pairs of experimental Columbiads that have been proved, or partly proved, the hollow cast has shown a marked superiority in every instance.

2 Pairs 8-inch Columbiads.

Solid guns fired 158 rounds — both burst.
Hollow guns fired 1751 rounds — one gun unbroken.

3 Pairs of 10-inch Columbiads, of which one or both Guns have broken.

Solid guns fired 445 times — guns all broken.

Hollow guns fired 2164 times — one gun unbroken.

One pair of 10-inch guns remains unbroken, each gun having been fired 2452 rounds.

Ratio of Good and Bad Guns.

Out of seven solid cast experimental Columbiads, *one* gun only proved to be good.

Out of six hollow cast Columbiads, *three* were good, having been fired 1500, 1600, and 2452 rounds respectively, and neither gun broken.

It is not deemed out of place here, in order to show the necessity of further investigations into the properties of cast iron, in its application to the manufacture of cannon, to notice some facts in the history of gun foundering in this country since 1849.

The very low endurance of the first pair (8-inch) of experimental guns which were cast in that year, was attributed to the inferior quality of the iron of which they were made.

Two years were spent in searching after a better quality of iron, which was undoubtedly found; and in 1851 another pair of 8-inch guns was cast.

The iron in this pair of guns had a tenacity of near 38000 lbs.; while that of the iron in the first pair was only between 27000 and 28000 lbs.

The solid cast gun of the first pair burst at the 85th fire, and that of the second pair at the 73rd fire; the superior iron giving the inferior solid cast gun.

These results did not, however, destroy confidence in strong iron for solid cast guns, and the first pair of 10-inch guns was made from the same lot of iron; and, with a tenacity of iron of 37000 lbs., the solid cast gun burst at the 20th fire. This result weakened confidence in very strong iron, and the tenacity was reduced.

In 1857, after guns of good tenacity had failed at the Fort Pitt, South Boston, and West Point foundries, four out of seven guns offered for inspection at the last named foundry having burst in the proof, Mr. Parrott, proprietor of the West Point foundry, one of our most experienced gun founders, cast his *trial* contract guns of iron, having a tenacity of 30000 to

32000 lbs.   One of these guns has endured 1000 service charges of 14 lbs. powder (800 rounds with shells, and 200 with shot).

The iron selected at that foundry, and from which the last five experimental guns have been made, was of the same quality, and in the same proportions, as in the guns last above referred to.

In 1858, after the failure, at the 169th fire, of the West Point experimental gun made from this iron, Mr. Parrott condemned it as being *too high* for heavy guns.

From this rejected iron was made the last pair, Nos. 362 and 363, of trial 10-inch guns, at the Fort Pitt foundry, which have been fired 2452 rounds each; the least charges fired being 14 lbs. powder and one solid shot, and neither gun broke.   These guns have since been fired one thousand rounds each, with 18 lbs. of powder and solid shot, and neither gun yet broken.

It should also be borne in mind that the proprietors of the West Point foundry have control of the smelting furnace at which their gun iron is made; they ought, consequently, to have a more perfect knowledge of the qualities and properties of their iron, than those founders who are dependent upon the market for their gun iron.

These facts, to my mind, are conclusive as to the fact that we are at present far from possessing a practical knowledge of the properties of cast iron in its application to gun foundering; and it is too much to expect of private enterprise to take up and prosecute so intricate and expensive an inquiry.

The subject is one of national importance; and until the Government shall obtain control of a smelting furnace and a foundry for casting cannon, it is, in my judgment, in vain to look for any marked improvement on our present knowledge of this subject.

<div style="text-align:right">T. J. RODMAN,
<i>Capt. of Ordnance.</i></div>

Having witnessed the operations of casting the trial guns cast at the Fort Pitt foundry, — two on the 13th August, 1857, and two on the 11th August, 1858, respectively, — I concur in statement of facts relative to the mode of conducting these operations, as made by Capt. Rodman, in the foregoing Report.

<div style="text-align:right">S. CRISPIN,
<i>Lieut. of Ordnance.</i></div>

REPORT

OF

EXPERIMENTS

MADE BY

CAPT. T. J. RODMAN, U. S. ORDNANCE DEPARTMENT,

IN THE YEARS 1857 & 1858,

FOR DETERMINING THE PROPERTIES OF GUN METAL,

AND THE

ACTUAL PRESSURE PER SQUARE INCH DUE TO DIFFERENT

WEIGHTS OF POWDER AND SHOT.

REPORT

OF

EXPERIMENTS MADE AT ALLEGHANY ARSENAL, BY CAPTAIN T. J. RODMAN, U. S. ORDNANCE DEPARTMENT, IN THE YEARS 1857 AND 1858, FOR DETERMINING THE PROPERTIES OF GUN METAL, THE RESISTANCE WHICH GUNS CAN OFFER TO A BURSTING FORCE, THE ACTUAL PRESSURE PER SQUARE INCH DUE TO DIFFERENT WEIGHTS OF POWDER AND SHOT, ETC., ETC.

Transverse Resistance of Guns.

FOR the purpose of determining data which enter the general formula for the bursting tendencies of different weights of powder and shot on guns of different calibre and thickness, the following experiments were made, viz. : —

Nine bars of iron, 22 inches long, were cast on their ends in dry sand moulds, and from the same ladle of metal.

Six of these bars were similar, and equivalent in cross section to the staves which would be cut from a 6-pdr. gun, one calibre thick, by planes through its axis, their thin or inner edges being 1.125 inches thick.

These bars were dressed on their sides and on their thin edges, their outer edges having the same curvature as that of a 6-pdr. gun, one calibre thick.

The other three bars were of rectangular cross section, breadth, $b = 2.24$ in., and depth, $d = 3.45$ in., and dressed on all their sides ; they were all broken transversely — three of the stave-shaped bars with their thin edges up, and the other three with these edges down.

The distance between the outer bearings was 20 inches, and the breaking force was applied at the middle point of this distance, and acted in a vertical direction, upward.

The mean breaking weight of the three broken with their thin edges down was 39686 lbs.; while that of the three broken with their thin edges up was 35433 lbs. The mean breaking weight of the three rectangular bars was 38456 lbs.

The transverse strength of this iron, as determined from the mean breaking weight of the three rectangular bars, by the formula $S = \dfrac{L\,W}{4\,b\,d^2}$, is 7212 lbs.; and, knowing this element, we can determine the breadth of a bar, of rectangular cross section, and depth equal to that of the stave-shaped bars, whose transverse resistance is equal to that of the stave-shaped bars with either edge down. This has been found to $= 2.099$ inches with the thin edges down.

A stave of the same length and same iron as above, one inch thick on their edge and sides in direction of radii, would bear eight-ninths of the weight borne by these bars. And since in the gun the staves are fixed at their extremities, and have the pressure uniformly distributed along their whole length, the total resistance which a single stave, one inch thick on its inner edge, could offer, would be $= \frac{8}{9}\,(39686 \times 2 + 35433) = 102050$ lbs.

And the breadth of a bar of same length and depth, and of rectangular cross section, which would offer an equal resistance, would result from the formula for the transverse resistance of a bar fixed at its extremities, and having its load uniformly distributed along its whole length, viz., $b = \dfrac{L\,W}{12\,S'\,d^2}$; in which $b =$ breadth of bar, $d =$ depth, $L =$ length, $W =$ load, and $S' =$ transverse strength of the material of which the bar is made.

The breadth of a bar which would equal in depth and transverse resistance a stave one inch thick on inner edge, cut from a gun one calibre thick, as determined by the above formula, has been found, by computation, to be 1.8 in.

The metal from which these results were obtained was quite soft. Harder metal, it is believed, would have given a greater difference in the resistance of the stave-shaped bars, due to a reversion of position of broad and narrow edges, and this would have increased the breadth of the equivalent rectangular bar; so that it is believed that, for gun metal, two inches would be nearer the truth than 1.8, and the following law would result, viz.: —

The total transverse resistance which a stave of a gun can offer is equal to that which a bar of rectangular cross section, and same metal, length, and depth, and whose breadth $=$ mean of inner and outer edges, would offer

when fixed at its extremities, and having its load uniformly distributed along its whole length.

Deflection of Bars under Loads equally distributed along their Whole Lengths.

For the purpose of determining the relation between the length and the deflection or sag of bars of rectangular cross section, and of uniform breadth and depth, when supported at their extremities in a horizontal position, and having their loads uniformly distributed along their whole length, the following experiments were made, viz. : —

A slip of white pine, well seasoned and straight grained, was accurately dressed to a uniform breadth and depth along its whole length, which was, at first, ten feet.

This slip was placed in a horizontal position, its length between its bearings being 10 feet, and its sag or deflection at its middle point accurately measured; it was then turned over and placed on the same bearings, and its sag again measured. A mean of these measurements was taken as the true sag. One foot in length was then cut from each end, and the sag again measured in the same manner as before.

This process was continued till the slip was reduced to two feet in length. The deflections thus determined are as follows, viz. : —

For a length of 10 feet, sag = 6.595 inches.
 " " " " 8 " " = 2.725 "
 " " " " 6 " " = .898 "
 " " " " 4 " " = .199 "
 " " " " 2 " " = .015 "

These deflections are very nearly proportional to the fourth powers of the lengths, and accord very closely with the theory on this subject, as given in Boucharlat's Mechanics.

Transverse Resistance of Hollow Cylinders.

For the purpose of determining the value of the transverse resistance offered by hollow cylinders to a bursting force, acting upon different lengths of bore, the following experiments were made, viz. : —

Three solid cylinders of iron, 4 inches diameter and 8 feet long, were cast on their ends in dry sand at the same time, being poured from the same ladle of metal.

These cylinders were marked *A*, *B*, and *C*. From the lower end of each of these cylinders was taken one specimen 10 inches long, and numbered (1). These specimens were all turned to an exterior diameter of 3.384 in., and bored to an interior diameter of 1.128 in., leaving a thickness of metal below the bottom of the bore, which terminated in a hemisphere, equal to twice its diameter, the bottom of the cylinder being cut square off.

At the muzzle ends of the cylinders were left collars, by which they were suspended in another cast iron cylinder while the bursting pressure was being applied, in order that they might be subjected to a longitudinal strain at the same time, as is the case in the discharge of fire-arms.

A mean of the results obtained from these three cylinders was taken as the true one, since they were all broken under the precise same circumstances.

Other sets of specimens of the same form and dimensions were taken from these cylinders, each set being numbered in regular order from the lower ends of the cylinders upwards, and broken under the same circumstances, except that the length of bore subjected to pressure varied in the different sets.

The bursting force was produced by filling the specimens to the height required with bees-wax, and pressing upon it with an accurately fitting steel piston, the pressure being exerted by the testing machine, by which a pressure of 100000 lbs. can be exerted, and accurately weighed.

In order to prevent the bees-wax from forcing up around the piston, cups made of sole leather, which accurately fitted the bores of the cylinders, were inserted, with their mouths downward, upon the wax, before inserting the piston.

Bees-wax was used instead of water in these experiments, for the reason that water was forced through the pores of the iron at a pressure of 11000 lbs. per square inch.

PLATE I.

Curves expressive of the Transverse and Tangential resistances, offered by hollow Cylinders to bursting forces, applied to different lenghts of bore.
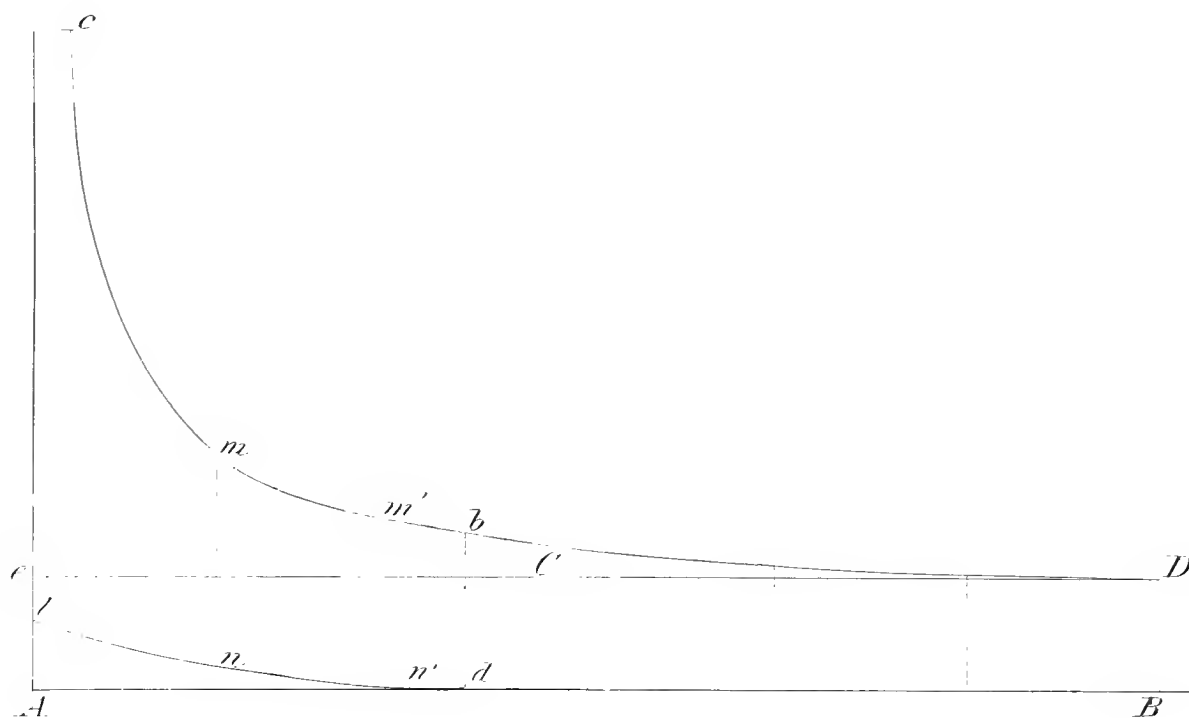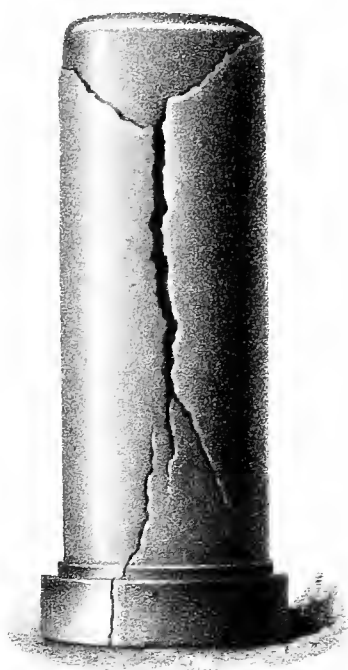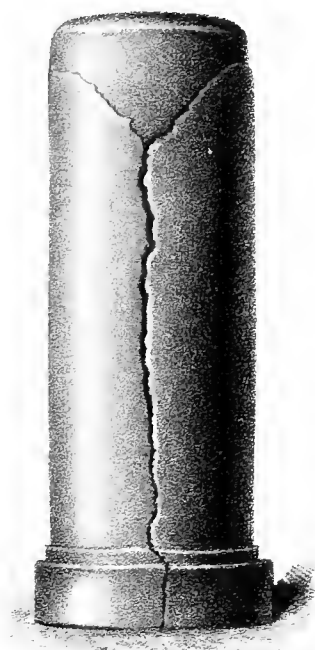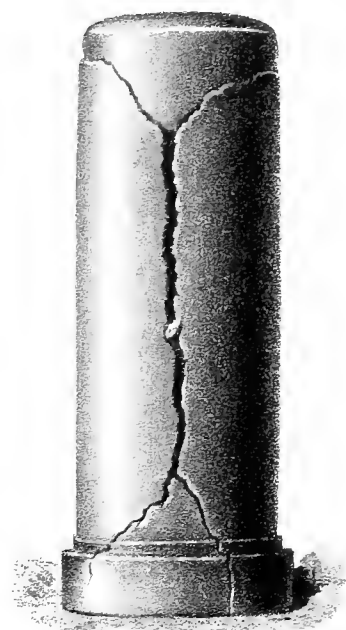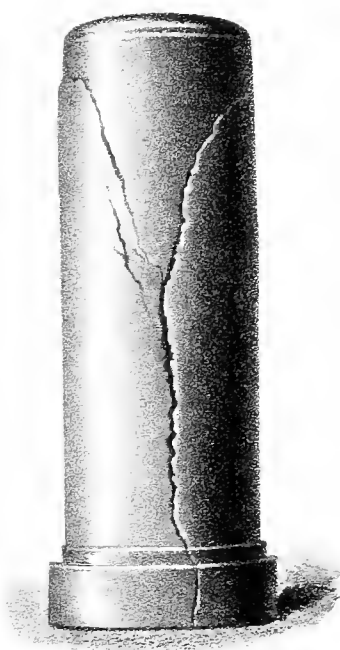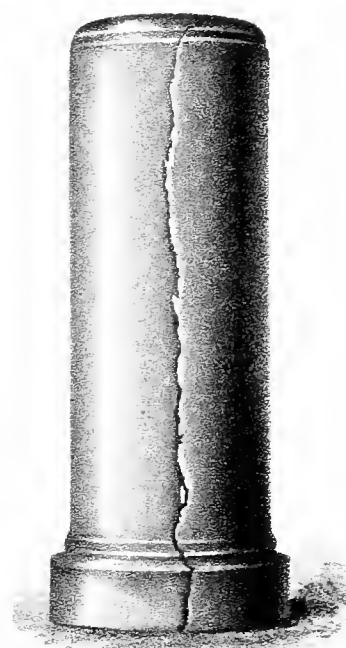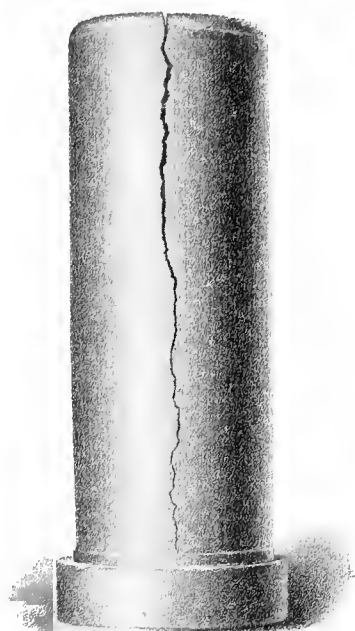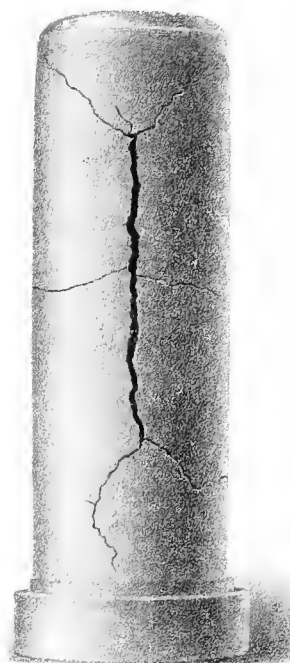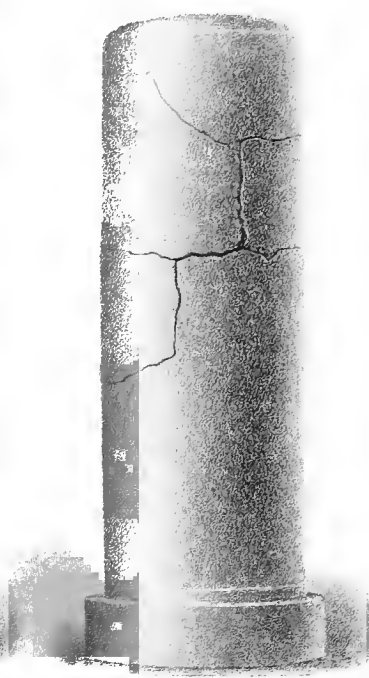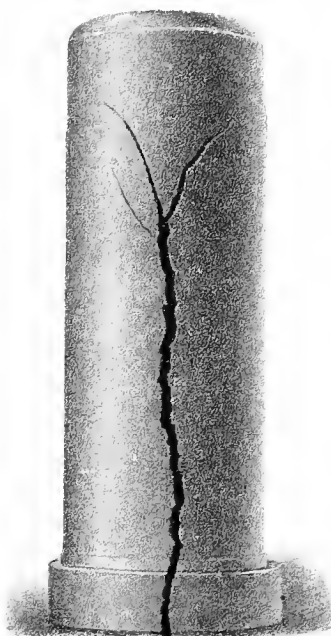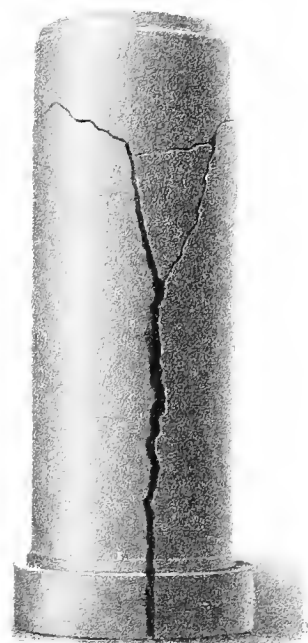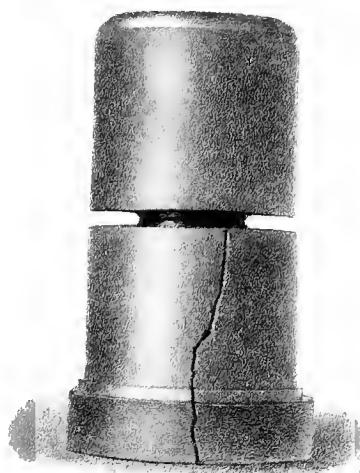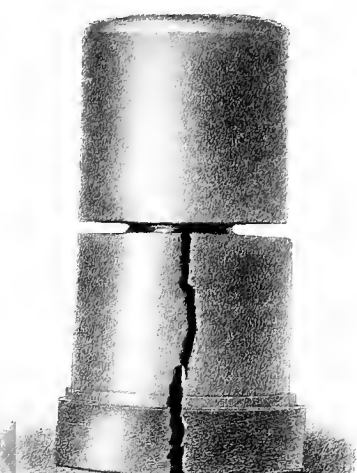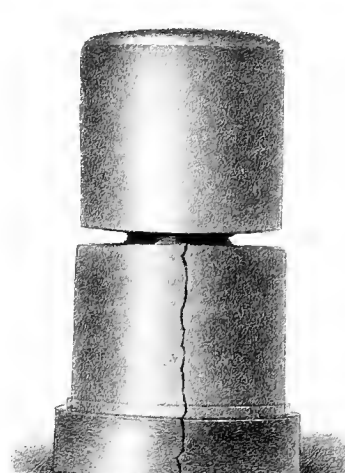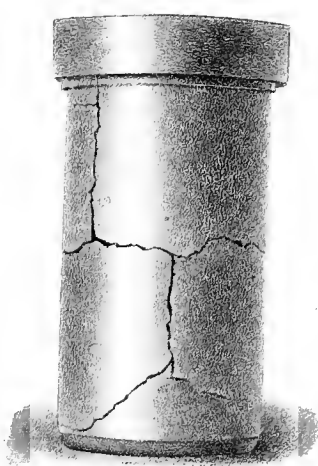
PLATE II.

PLATE III.

A.3   B.3   C.3.

A.4   B.4   C.4

PLATE IV.

A.5.

B.5.

C5

A.6.

B.6.

C.6.

.

PLATE V

A.8.   B.8.   C.8.

A.9   B.9   C.9.

PLATE VI

A.10. B.10 C.10

PLATE VII.

D.1.   E.1.   F.1.

D.2   E.2   F.2

PLATE VIII.

D3.

E3.

F3.

D4.

E4.

F4.

C H Crosby Lith.

PLATE IX.

D.5

E.5.

F.5

D.6.

E.6.

F.6.

PLATE X.

D. 7.

E. 7.

F. 7.

D. 8.

E. 8.

F. 8.

PLATE XI
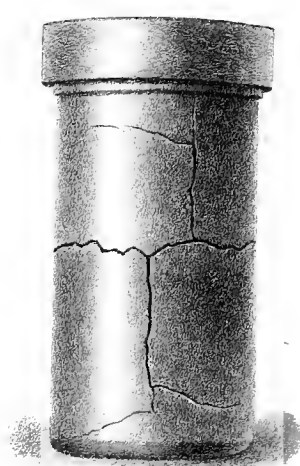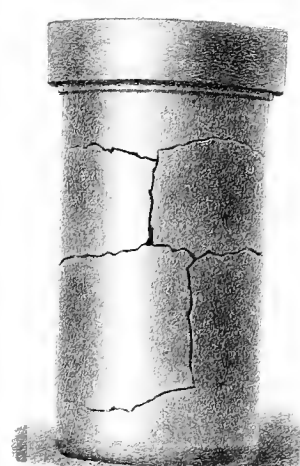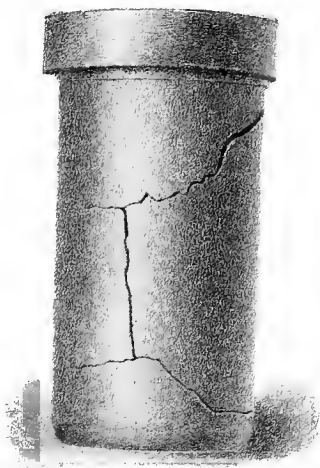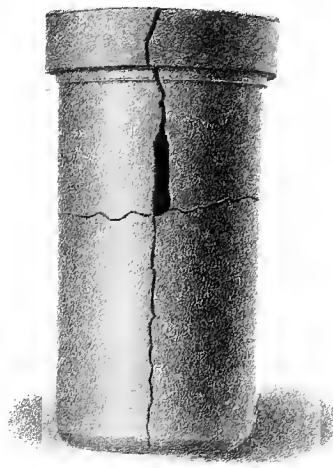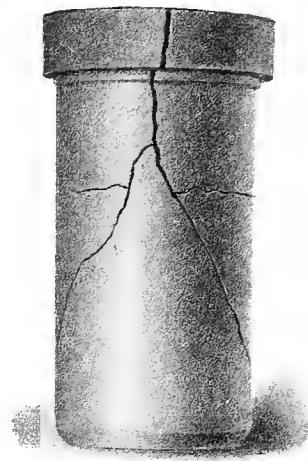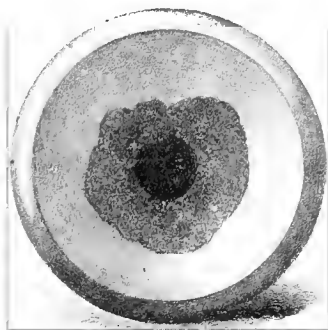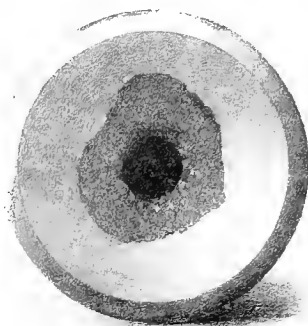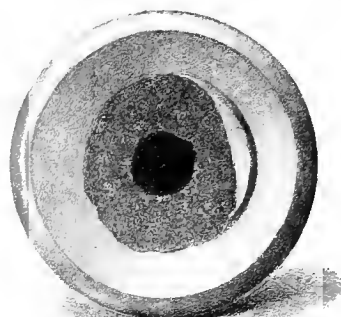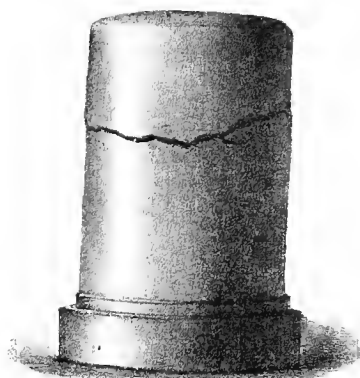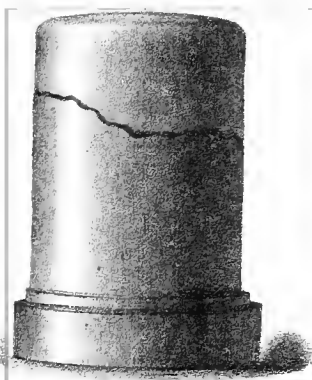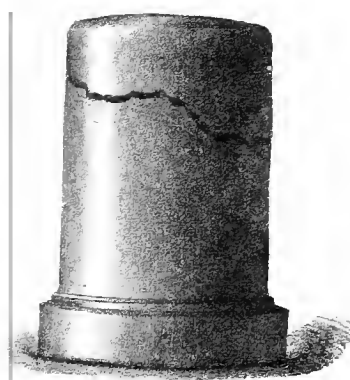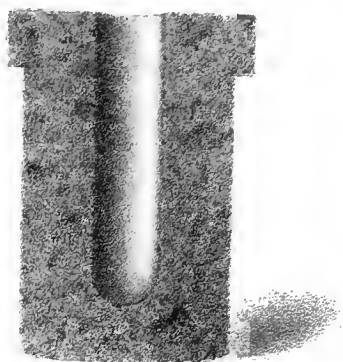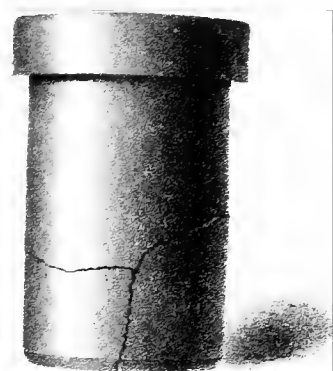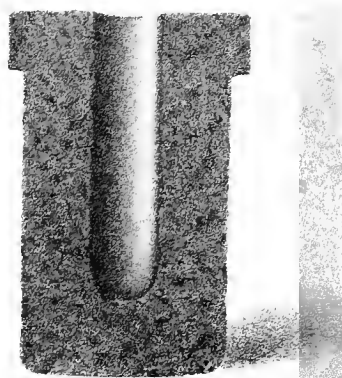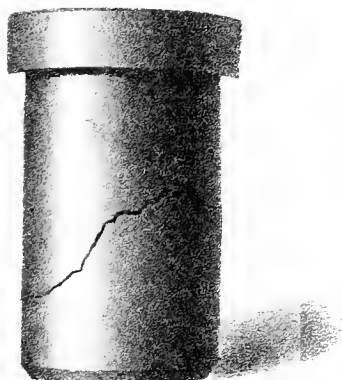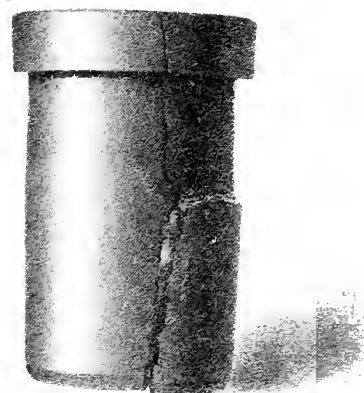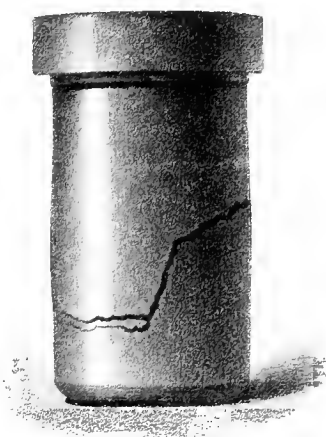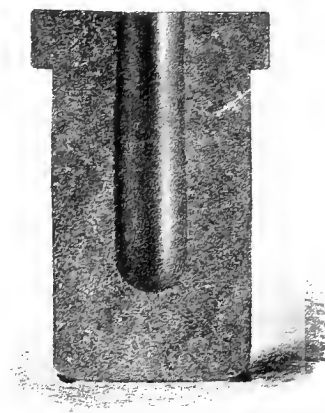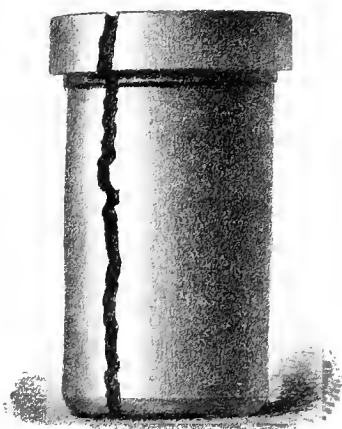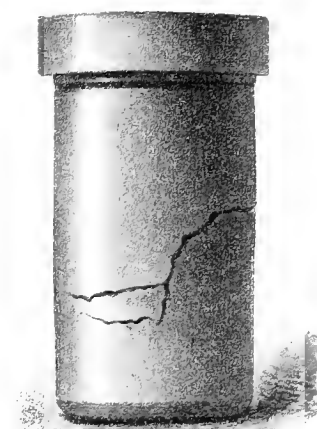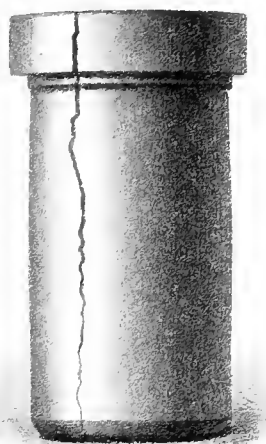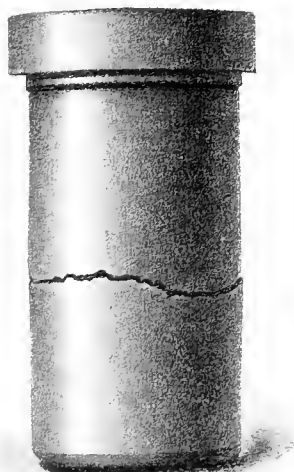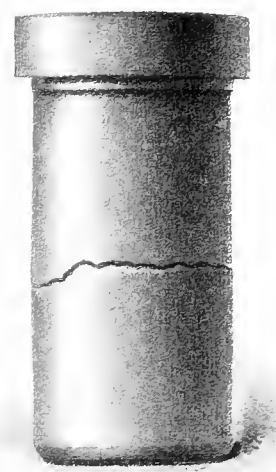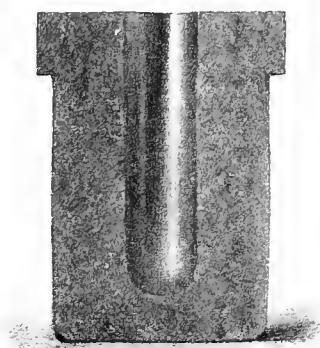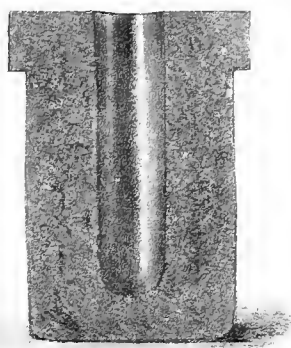
D.9   E.9   F.9
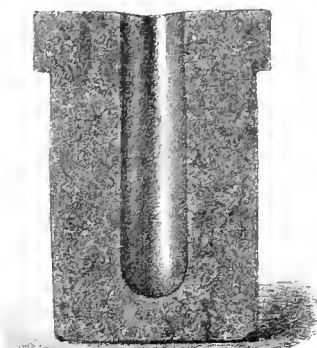
The following table gives the results obtained from 10 sets of specimens:—

Number of Sets of Specimens.	BURSTING PRESSURE.			DIAMETERS.		Length of surface pressed.	Mean bursting pressure.
	A	**B**	**C**	Interior.	Exterior.		
1	62000	42600	56450	1.128	3.384	6 inch,	53683 lbs.
2	69000	51150	40000°	1.128	3.384	5 "	60075
3	40000°	72000	70550	1.128	3.384	4 "	71575
4	80200	80800	72900	1.128	3.384	3 "	77966
5	86000	87075	89800	1.128	3.384	2 "	87625
6	60000	64850	56950	1.128	3.384	7 "	60600
7	74000	Broke in	preparation.	1.128	3.384	2 "	74000
8	63800	62900	71000	1.128	3.384	2 "	65917
9	94400	86600	89600	1.128	3.384	2 "	90200
10	96350	92650	93675	1.128	3.384	2.6 "	94225

* These specimens broke by splitting, one (C 2) through the muzzle end, and the other (A 3) through the solid end. Both are regarded as defective, and not included in the mean results.

It was believed, before commencing these experiments, that the transverse resistance would diminish as the length of bore, subjected to pressure, was increased; and that beyond a certain length, which was not believed to be more than four or five inches, it would be inappreciable; and it was intended to begin with such a length of surface, pressed, in these experiments.

Set No. 2, however, gave a greater resistance than No. 1; therefore, after diminishing the length of surface pressed to two inches, with a constantly increasing resistance, set No. 6 was burst with seven inches length of surface pressed, the resistance being greater than that given by set No. 1, with six inches length of surface pressed, and about equal to that of set No. 2, with five inches surface pressed; from which it is concluded that the transverse resistance is inappreciable beyond five calibres in length, with a thickness of metal of one calibre.

The results recorded in the foregoing table show a rapid increase in resistance as the surface pressed diminishes; and inspection of the re-assembled fragments (see Plates 2 to 11 inclusive) gives additional proof that it is due to the increase in transverse resistance.

All the specimens of sets Nos. 1, 2, and 6, broke by splitting longitudinally, without any indication of transverse fracture; those of set No. 5, which had four inches in length of surface pressed, split longitudinally, but the fragments had small transverse *cracks* just opposite the middle of the length of

37

surface pressed; showing that the transverse strain had been greater in these specimens than in those having a greater length of surface pressed, and that the tangential resistance had been first overcome.

In set No. 4, with three inches length of surface pressed, specimen A broke, first transversely, and then longitudinally; while B and C both broke, first longitudinally, and then transversely, as shown by the fact that the middle line of transverse fracture is continuous in (A), and the lines of longitudinal fracture on opposite sides of this line terminate abruptly, at different points upon it, while the lines of longitudinal fracture are continuous in (B) and (C), and those of transverse fracture terminate abruptly, and at different points, upon them; the *rule* in this set being, that longitudinal rupture first supervened.

The same reasoning, upon the lines of fracture in set No. 5, with two inches length of surface pressed, shows that the *rule* in this set clearly is, that transverse rupture first supervened. It follows from these facts that the length of surface pressed, necessary to produce transverse and longitudinal rupture simultaneously, or to fully develop both the transverse and tangential resistances in these cylinders, is between two and three inches, and nearer to two than three.

In order further to investigate the value of the transverse resistance, another set of cylinders (No. 7) was prepared, of the same form and lateral dimensions as those used in previous trials, except that they had transverse grooves turned in them at the middle of the length of surface pressed, so as to cut off a portion of the transverse resistance, without in any material degree affecting the tangential resistance, the grooves being .125 inch wide, and of such a depth as to leave .125 in. of metal around the bore at that point.

Two of these specimens broke in preparation, and the other burst at 74000 lbs.; while those of set No. 5, with the same length of surface pressed, gave a mean of 87625 lbs. Not being satisfied with a single result, I caused another set (No. 8) to be prepared, similar in all respects to set No. 7, except that there was left at the bottom of the grooves .25 in. instead of .125 in. of metal. The mean bursting pressure of this set was 65917 lbs.; and, including the tested specimen of set No. 7, the mean bursting pressure of the four specimens was 67925 lbs.

These grooves did not cut off the whole of the transverse resistance, but

only that portion which the staves would offer against being bent outwards if merely *supported*, instead of being *fixed* at their extremities, leaving the resistance which the fixed ends of the staves could offer unimpaired.

The formula for the load which a bar of rectangular cross section can bear, when fixed at its extremities, and having the load uniformly distributed along its whole length, is $W = \dfrac{12\ S'\ b\ d^2}{l}$; while that for the load which the same bar would bear if merely supported at its ends, is $W = \dfrac{8\ S'\ b\ d^2}{l}$; and it is this portion of the transverse resistance which the grooves cut off.

If, therefore, the staves were of rectangular cross section, the grooves ought to cut off two-thirds of the whole transverse resistance; but since they are thicker on their outer than on their inner edges, the grooves ought to cut off more than two-thirds; experiment having shown (page 141) that a bar, similar in cross section to the staves which would be cut from a 6-pdr. gun one calibre thick, by planes through its axis, offers a greater transverse resistance when the thick edge is bent outwards, than when the thin edge is outward, in the proportion of 112 to 100.

Therefore the transverse resistance cut off by the grooves should be to that remaining as 112 : 50.

If we take a mean of the results obtained from sets of specimens Nos. 1, 2, and 6, for the true tangential resistance, we find it to = 58123 lbs.; while the mean total resistance of sets Nos. (5) and (9) = 88912.

The whole transverse resistance, therefore, (88912 — 58123) = 30789 lbs.

The amount of transverse resistance cut off by the grooves = (88912 — 67925) = 20987 lbs.; while that remaining = (30789 — 20987) = 9802 lbs.

The transverse resistance cut off by the grooves is therefore to that remaining, as 20987 to 9802, or in a proportion greater than two to one; and corresponding almost exactly with the previously determined ratio of 112 to 50.

These results leave no doubt of the existence of a transverse resistance to the rupture of a hollow cylinder by a central force, when that force acts upon only a portion of the length of the cylinder.

They also show this resistance to be equal to about one-half of the tangential resistance for two calibres length of surface pressed, and that it rapidly diminishes as the length of surface acted upon increases, being scarcely appreciable beyond five calibres in cylinders one calibre thick. The value of

this resistance depends, also, upon the thickness of metal and diameter of bore of the cylinder.

In order to determine the value of this resistance as an auxiliary to the tangential resistance, we regard the staves of which we may suppose the cylinder to consist, as being fixed at their extremities, and having the pressure to which they are subjected equally distributed along their whole length.

The formula for the transverse resistance of a bar of rectangular cross section, thus circumstanced, is $W = \dfrac{12\ S'\ b\ d^2}{l}$, in which $W =$ breaking weight, S' transverse strength of material, $b =$ breadth, $d =$ depth, and $l =$ length of bar.

This formula gives the value of the transverse as an *auxiliary* to the tangential resistance, for that particular length of surface pressed, at which transverse and longitudinal rupture supervene simultaneously; but for all lengths greater than this, the staves offer only so much transverse resistance as equals the force required to produce in them a deflection, or sag, equal to half the increase in diameter of the bore, due to the tangential extension of the metal at the moment of rupture. But the amounts of sag produced in the same bar by different weights are, within certain limits, directly proportional to those weights.

And both theory and experiment show that the sag produced in bars of the same cross section and material, but of different lengths, will be, when loaded with equal weights per unit of length, directly proportional to the fourth powers of their lengths. (See page 143.)

If, therefore, $\dfrac{12\ S'\ b\ d^2}{L} =$ the resistance which a single stave *could* offer, if bent to its breaking deflection, and $x =$ that which it does offer at the moment of tangential rupture, $d' =$ sag which it *could* undergo, $e =$ extension of metal per inch of length at the moment of rupture, $r =$ radius of bore, $l =$ length of surface pressed at which transverse and longitudinal rupture supervene simultaneously, and $L =$ any other length of stave or surface pressed, we shall have the proportion $\dfrac{12\ S'\ b\ d^2}{L} : x :: d' : e\ r :: L^4 : l^4 :$ or $x = \dfrac{12\ S'\ b\ d^2\ l^4}{L^5}.$

The value of (l) is thus determined. Suppose a stave to be bent, with its thick edge outward, around a circle of such diameter that the exterior of the stave shall be just at the breaking strain; then twice that arc of this circle, whose versed sine is equal to $e\,r$, will be the value of (l). Let R = radius of this circle, t = thickness of metal in the cylinder; then if we assume the neutral axis of the stave to be at its

* For the very small value of the arc subtended by $\frac{1}{2}\,l$, the sine and arc are regarded as equal.

inner surface, as it doubtless will be very nearly under the simultaneous action of the longitudinal strain, we shall have, as shown by the figure,

$e : t :: 1 : R'$, or $R' = \dfrac{t}{e}$, and $l = \dfrac{t}{e} 2$ sine of arc to versed sine $\dfrac{e^2\,r}{R-r}$. But

$d = t$, and $S' = \dfrac{S}{4}$; or the transverse unit of strength is one-fourth that of the tensile, and the value of x, as above, is the resistance offered by a single stave; but experiment has shown (page 142) that each stave offers a resistance equal to that which would be offered by a bar of rectangular cross section, whose depth = that of the stave, and whose breadth = the mean thickness of the outer and inner edges of the stave.

And since the resistance offered by the staves is in the direction of radii, or planes through the axis of the cylinder, their total resistance will be estimated on the same principle as the bursting effort of a central force; or, if the staves were of the same thickness on their inner and outer edges, then their total resistance to the rupture of one side of the cylinder would be $\dfrac{12\;S'\;r\,d^2\,l^4}{L^5}$, the radius of the bore being substituted for the breadth of the stave.

But, since each stave offers as much resistance as would be offered by a bar of rectangular cross section, and same depth, whose breadth = mean thickness of inner and outer edges of the stave, this resistance will become, by substituting $\dfrac{R+r}{2}$ for r, $\dfrac{12\;S'\left(\dfrac{R+2}{2}\right)d^2\,l^4}{L^5}$, in which R = exterior radius of cylinder; but (d), in this expression, is the depth of the bar or stave, and is equal to the thickness of metal in the cylinder, and therefore

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$= t = (R - r)$; and substituting this value of (d), and for S' its value $\dfrac{S}{4}$, we have the total transverse resistance to the rupture of one side of the cylinder $= \dfrac{12 \, \dfrac{S}{4} \left(\dfrac{R+r}{2} \right) (R - r)^2 \, l^4}{L^5} = \dfrac{3 \, S(R + r) \, (R - r)^2 \, l^4}{2 \, L^5}.$

With a view to determine the degree of coincidence between the value of (l), as determined in these experiments, and that given by the equation $l = \dfrac{R - r}{e} \, 2 \left(\text{sine of arc whose versed sine} = \dfrac{e^2 \, r}{R - r} \right)$, let us assume $e = .0029$, which is the mean value deduced from four bars, each 35 inches long, cut from 10-inch Columbiads Nos. 335 Fort Pitt, and 983 West Point.

In these cylinders $(R - r) = 1.125$, and $r = .5625$; therefore $\dfrac{e^2 \, r}{R - r}$ $= .0000042 = $ nat. versed sine of $0° \, 10'$.

And by the proportion radius : sine $0° \, 10' :: \dfrac{R - r}{e} : \dfrac{l}{2}$, we have $\dfrac{l}{2} = \dfrac{R - r}{e}$ $\dfrac{\text{sine } 0° \, 10'}{\text{radius}} = 1.128$, and consequently $l = 2.256$. Now it has been shown, by reasoning upon the lines of fracture (page 146), that with three inches length of surface pressed, the *rule* was that the cylinders first broke longitudinally; and that with two inches length of surface pressed, the rule was that they first broke transversely; and consequently that the length of surface pressed, necessary for the full development of both transverse and tangential resistance, was between two and three inches. The foregoing calculation gives it $= 2.256$ in., while the lines of fracture of sets of cylinders Nos. 4 and 5, indicate that it is nearer to two than three inches.

The coincidence is sufficiently close to show that, notwithstanding the very minute quantities which enter the calculation and which have to be mechanically measured, the results are reliable.

The value of the transverse as an auxiliary to the tangential resistance is, perhaps, more clearly shown by the diagram (Plate 1) constructed from the tabulated results. This diagram is constructed as follows, viz. : — The axis of abscissa is assumed to be parallel to that of the gun, and the axis of ordinates corresponds, in position, with the bottom of the bore.

The diameter of bore and thickness of metal are assumed to be the same as those of the cylinders from which the tabulated results were obtained.

The points at which the *total* resistance was determined will therefore be at

2, 3, 4, 5, 6 and 7 inches from the origin of co-ordinates. Then, if the gun be of uniform thickness throughout its length, its tangential resistance will likewise be uniform for all lengths of surface pressed, greater than that which fully develops the transverse resistance.

Then, since the total resistance does not sensibly diminish beyond about six calibres, the resistance at this point is the measure of the tangential resistance.

If, therefore, at the distance of 6 inches, the ordinate BD be erected, corresponding in value with the mean total resistance offered at 5, 6, and 7 inches, and through the point (D) the line DC be drawn parallel to AB, the distance between these lines will represent the tangential resistance for all lengths of surface pressed, greater than that which fully develops the transverse resistance.

The value of the transverse resistance will be shown by erecting at the distances 2, 3, 4, and 5 inches, ordinates corresponding in value with the total resistance due to these lengths of surface pressed, and through their extremities drawing the curve Db; the distance between this curve and the line DCe will correspond in value with the transverse resistance.

Both theory and experiment indicate that the transverse resistance is fully developed at about 2 calibres length of surface pressed; and of course it will be for all lengths less than this.

Therefore the transverse resistance for all lengths of surface pressed, less than 2 calibres, will be to that at 2 calibres, inversely as those lengths. The part (cb) of the curve (cbD) is therefore constructed in accordance with this law.

But the tangential resistance will not be fully developed for any length of surface pressed less than two calibres, and its value will be found by demitting from the curve ($c\ m\ m'\ b$) ordinates corresponding in value to the total resistance at the points for which the tangential resistance is required.

Thus at 2 inches the ordinate $m'\ n'$ is drawn, corresponding in value with the total resistance at 2 inches, and at 1 inch the ordinate $m\ n$, corresponding with the total resistance at one inch, and through the extremities of these lines the curve $l\ n\ n'$ is drawn.

The total resistance at one inch is computed from knowing that of a weaker specimen at one and two inches; the resistance of the cylinders from which the other results were obtained being beyond the capacity of the testing machine at one inch.

That portion of the curve *l n n′ d*, which lies betwen *l* and *n*, is hypothetical, as we have no results for such short lengths of surface pressed; but we know that the tangential resistance which the gun or cylinder offers will diminish as the surface pressed diminishes from this point; and that if the diameter at the bottom of the bore should not be increased by the pressure, this resistance would be zero at that point. Under this supposition the point (*l*) would fall at (*e*,) but the solid metal at the bottom of the bore is doubtless affected, and the diameter at that point increased by a pressure which will produce rupture; and it will probably not be far from the truth to suppose the tangential resistance to be one-half developed at the bottom of the bore, which would place (*l*) intermediate between (*A* and *e*). The distance between the lines *c D* and *l B* corresponds to the total resistance; that part above the line *e D* representing the transverse, and that below, the tangential resistance. The ordinates corresponding to resistance to rupture are on a scale of .01 of an inch per 1000 lbs.

Effect of Chambers on Endurance of Guns.

With a view to determine in what manner the resistance of cannon to the explosive force of gunpowder is affected by the use of the chamber, two other sets of cylinders, Nos. 9 and 10, were prepared, of the same form and dimensions as those of sets Nos. 7 and 8, except that they had no transverse grooves; and set No. 10 had chambers exactly proportional to that of the 10-inch Columbiad.

These two sets of cylinders were broken by pressure upon *equal weights* of wax in each. This gave different lengths of surface pressed, as shown in the table; the difference being proportional to what would occur in the 10-inch Columbiad by the use of equal weights of powder in guns with and those without chambers, supposing the shot to be rammed home, and that no space is left around the cartridge.

The results obtained from these two sets of cylinders show those with chambers to be the strongest, though the difference is not sufficiently marked to remove the suspicion which lies against the use of the chamber.

For although, as in this instance, the chambered specimens might in all cases offer a greater ultimate resistance to a single application of a slowly applied force, yet, for the reasons given at page 48 of my Report of Experiments in 1856, it by no means follows that they would resist a greater number of

repetitions of a suddenly applied force, of less intensity than that which would produce rupture at a single application.

Experiments on guns cast from the same heat, same iron, cooled and proved under precisely similar circumstances throughout, one with and the other without chamber, are required, to give a practical solution to this question, which is believed to be of sufficient importance to justify the experiments.

Thickness of Metal in the Breech.

For the purpose of determining the proper thickness of metal in the breech of cannon, three other cylindrical bars of iron, marked *D*, *E*, and *F*, were cast in dry sand moulds at the same time, and from the same ladle of melted metal.

From these bars were prepared nine sets of cylinders, of the same lateral dimensions as those already described, the sets being numbered from the lower ends of the bars upward, and having collars turned around their muzzle ends, on which they hung during the application of the bursting force.

All the dimensions of the different sets were the same, except the thickness of metal in the breech.

The results of this set of experiments are recorded in the following table : —

Number of sets of Specimens.	BURSTING PRESSURE.			Thickness of Metal in Breech.	Length of surface pressed.	Mean bursting weight.
	D	**E**	**F**			
1	39150	38250	34500	$\frac{1}{4}$ calibre,	2 calibres,	37300
2	57700	58850	56800	$\frac{1}{2}$ "	2 "	57783
3	52200	50730	52750	$\frac{3}{4}$ "	3 "	51893
4	52430	51400	52820	1 "	3 "	52217
5	52580	52600	52660	$1\frac{1}{4}$ "	3 "	52613
6	52050	52800	52600	$1\frac{1}{2}$ "	3 "	52483
7	52700	52450	52800	$1\frac{3}{4}$ "	3 "	52650
8	73600	71450	71150	2 "	1 "	72066
9	49200	48300	49800	$\frac{1}{2}$ "	3 "	49100

Set No. 1 all broke, by having the bottom forced out. Set No. 2, with two calibres length of surface pressed, broke transversely at the middle of the length of surface pressed, showing cracks in the exterior of the bottom, but

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no longitudinal cracks; thus showing conclusively that by the joint action of the transverse and longitudinal strains, the specimens were broken transversely and pulled asunder longitudinally, before the tangential resistance had been fully developed; while set No. 9, (which was prepared to replace set No. 2,) with 3 calibres length of surface pressed, all split longitudinally. Showing that with the greater length of surface pressed, the tangential resistance was overcome before the transverse had been fully developed; and showing the length of surface pressed, required to fully develop both resistances, to be between two and three calibres, as has been previously shown theoretically.

Set No. 8, with one calibre length of surface pressed, broke transversely, and was pulled asunder, showing no sign of longitudinal fracture.

These results show that no important increase in resistance is obtained by increasing the thickness of metal in the breech beyond $1\frac{1}{4}$ calibres, and it is believed that $1\frac{1}{2}$ calibres would be a safe rule to adopt.

Tangential Resistance of Hollow Cylinders.

For the purpose of determining the relation between the tangential resistance to a bursting force, the tensile strength of the metal, and the thickness of the walls of hollow cylinders, three other iron bars, *G*, *H*, and *I*, of circular cross section, were cast in dry sand at the same time, and from the same ladle of metal.

These bars were cast smaller at their lower ends, and increased by steps, or quick tapers, at intervals of eight inches; this being the length required to furnish a cylinder five inches long, and a specimen for tensile strength.

These bars were cast in this form, in order that the cylinders to be cut from them might have the same thickness of metal to be turned off in preparation, it being believed that this precaution would yield more accurate results than would be obtained by casting the bars of the same diameter throughout their length, and turning away the metal necessary to bring the smaller cylinders to the required exterior diameters.

The specimens for tensile strength were taken from the lower portions of the lengths of different diameters, each cylinder having its corresponding specimen for tensile strength contiguous to it.

The cylinders were five inches long, one inch in interior diameter, and varied from .2 to 1.2 in. in thickness of walls; the three cylinders cut

from corresponding parts of the three bars, being always of the same thickness. These cylinders were open at both ends, and were burst by filling them full of bees-wax, with leather packing at both ends, and forcing a steel piston into one end, while the other rested upon a plane surface of iron.

The following tables exhibit the results obtained:—

TABLE *showing Bursting Pressure, Mean Bursting Pressure per square inch, and Thickness of Metal.*

NUMBER OF SETS.	BURSTING PRESSURE.				Mean bursting pressure per square inch.	Thickness of metal.
	G	**H**	**I**	Mean.		
1	7815	7780	7420	7672	9768	.2 inches.
2	11750	12000	11250	11666	14854	.3 "
3	15830	15970	16000	15933	20286	.4 "
4	18455	18470	18700	18542	23610	.5 "
5	21650	21460	21460	21523	27404	.6 "
6	25000	25160	25190	25116	31979	.7 "
7	29560	28860	28500	28973	36890	.8 "
8	31070	28000	32555	30542	38887	.9 "
9	35225	35885	36255	35788	45566	1.0 "
{ 10*	30000†	39315	38950	39082	49760	1.1 "
{ 11	36000	43000	38370	39123	49813	1.2 "

* These sets are not regarded as fully reliable.
† Defective; not included in mean pressure.

These sets of specimens were numbered from the lower ends of the bar upward.

TABLE *showing the Tensile Strength and Density of Specimens contiguous to Cylinders referred to in the above Table.*

NUMBER OF SETS.	TENSILE STRENGTH.				Mean density.
	G	**H**	**I**	Mean.	
1	20188	21921	19520	20543	7.109
2	20516	17888	20569	19658	7.134
3	21467	21753	20201	21474	7.110
4	20190	20089	20558	20279	7.111
4	19765	19220	19572	19519	7.084
6	18895	19452	19388	19245	7.072
7	18886	19151	18506	18848	7.068
8	18973	18874	18815	18887	7.066
9	18882	18612	18967	18820	7.063
10	18992	19229	19061	19094	6.962
11	12095	14796	15672	14188	6.562

TABLE *showing the Mean Bursting Pressure per square inch of Cylinders, the Tensile Strength per square inch, and the Density of Tensile Specimens.*

Number of Sets.	Bursting pressure per square inch of cylinders.	Tensile strength per square inch of specimens.	Density of specimens.	Thickness of metal.
1	9768	20543	7.109	.2 inches.
2	14854	19658	7.134	.3 "
3	20286	21474	7.110	.4 "
4	23610	20279	7.111	.5 "
5	27404	19519	7.084	.6 "
6	31979	19245	7.072	.7 "
7	36890	18848	7.068	.8 "
8	38887	18887	7.066	.9 "
9	45566	18820	7.063	1.0 "
10	49760	19094	6.962	1.1 "
11	49813	14188	6.562	1.2 "

The diameters of the tensile specimens, at their points of rupture, were 1.2 inches.

These results are anomalous, and do not conform to theory on this kind of resistance.

These results, up to the 9th set, inclusive, show the resistance to increase almost directly as the thickness of metal; while, on the supposition that the metal is wholly incompressible, the resistance would be proportional to the Napierian logarithm of the thickness; and since we *know* that cast iron *is* compressible, the resistance ought to increase in a less ratio to the thickness.

These results also show the tangential resistance per square inch of section in the cylinders to be greater than the tensile strength per square inch.

Thus in set No. 1, the bursting pressure per square inch is 9768 = tangential resistance of .4 of one square inch, while four-tenths of 20543 = 8216; and this difference between the tangential and tensile resistance per square inch increases with the thickness of metal in the cylinders.

These discrepancies are partially explicable from the facts that the bees-wax used was not a perfect fluid, and that the tensile specimens were taken from the axial portions of the bars, and were probably not so strong as the outer portions which resisted the bursting pressure; but a comparison of the tensile strength of set No. 1, which was but little reduced from its cast diameter, with set No. 10, which underwent the greatest reduction from the cast diameter, shows a difference of only 1449 lbs., which would leave 6305 lbs.

to be accounted for by the imperfect fluidity of the wax; which is believed to be much more than should be attributed to that cause.

For the reasons above stated, these results are not regarded as entirely reliable; and as this is a very important element in the modelling of cannon, it is earnestly recommended that these experiments be repeated on a larger scale, and with a more perfect fluid, if one can be found that will not permeate the pores of the iron under the bursting pressure.

Extensibility and Compressibility of Gun Metal.

For the purpose of determining the extension per inch, in length, of cast iron, due to different weights borne, and its ultimate extension, or that due to the rupturing force, the following experiments were made, viz.: —

Four bars, 40 inches long each, were cut from each of the two 10-inch Columbiads, No. 983, cast solid at the West Point foundry, and No. 335, cast solid at the Fort Pitt foundry, both cast in 1857, and from the same quality of metal. Two of these bars, from each gun, were cut from near the surface of the bore, and the other two from near the exterior surface of the gun; they were all taken from the breech ends of the guns, and the middle of the length of the prepared specimens came from opposite the seat of the charge.

These specimens had collars left on them at a distance of 35 inches apart, the space between the collars being accurately turned to the same diameter throughout.

The space between the collars was surrounded by a cast iron sheath, eight-tenths of an inch less in length than the distance between the collars; it was put on in halves and held in position by bands, and was of sufficient interior diameter to move freely on the specimen.

When in position, the lower end of the sheath rested on the lower collar of the specimen, the space between its upper end and the upper collar being supplied, and accurately measured by a graduated steel scale tapered to .01 inch to 1 inch.

The upper end of the sheath was mounted with a vernier, and the scale was graduated to tenths of inches.

This apparatus afforded means of measuring the changes of distance between the collars, to the ten thousandth part of an inch, and these readings, divided by the distance between the collars, give the extension per inch, in length, as recorded in the following tables: —

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TABLE *showing the extension, restoration and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 inches long and 1.382 inches diameter, taken from near the surface of the bore of triplicate 10-inch Columbiad, No. 983, cast solid, at the West Point Foundry, in 1857.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.0000357	—	.0000357	—	—	—
2000	.0000714	.0000357	.0000714	.0000357	—	—
3000	.0001200	.0000486	.0001200	.0000486	—	—
4000	.0001742	.0000542	.0001685	.0000485	.0000057	—
5000	.0002171	.0000429	.0002057	.0000372	.0000114	.0000057
6000	.0002828	.0000657	.0002657	.0000600	.0000171	.0000057
7000	.0003314	.0000486	.0003114	.0000457	.0000200	.0000029
8000	.0003743	.0000429	.0003486	.0000372	.0000257	.0000057
9000	.0004371	.0000628	.0004057	.0000571	.0000314	.0000057
10000	.0004771	.0000400	.0004371	.0000314	.0000400	.0000086
11000	.0005800	.0001029	.0005257	.0000886	.0000543	.0000143
12000	.0006629	.0000829	.0005972	.0000715	.0000657	.0000114
13000	.0007400	.0000771	.0006600	.0000628	.0000800	.0000143
14000	.0008086	.0000686	.0007115	.0000515	.0000971	.0000171
15000	.0008943	.0000857	.0007772	.0000657	.0001171	.0000200
16000	.0009914	.0000971	.0008514	.0000742	.0001400	.0000229
17000	.0011288	.0001374	.0009545	.0001031	.0001743	.0000343
18000	.0012657	.0001369	.0010400	.0000855	.0002257	.0000514
19000	.0013715	.0001058	.0011058	.0000658	.0002657	.0000400
20000	.0014943	.0001228	.0011686	.0000628	.0003257	.0000600
21000	.0016600	.0001657	.0012600	.0000914	.0004000	.0000743
22000	.0018685	.0002085	.0013285	.0000685	.0005400	.0001400
23000	.0020885	.0002200	.0014028	.0000743	.0006857	.0001457
24000	.0023628	.0002743	.0015171	.0001143	.0008457	.0001600

TABLE *showing the extension, restoration and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 inches long and 1.366 in. diameter, taken from near the exterior surface of triplicate 10-inch Columbiad, No. 983, cast solid, at the West Point Foundry, in 1857.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.0000611	—	.0000611	—	—	—
2000	.0000794	.0000183	.0000794	.0000183	—	—
.3000	.0001089	.0000295	.0001089	.0000295	—	—
4000	.0001771	.0000682	.0001771	.0000682	—	—
5000	.0002129	.0000358	.0002129	.0000358	—	—
6000	.0002700	.0000571	.0002686	.0000557	.0000014	—
7000	.0003328	.0000628	.0003299	.0000613	.0000029	.0000015
8000	.0003986	.0000658	.0003943	.0000644	.0000043	.0000014
9000	.0004557	.0000571	.0004486	.0000543	.0000071	.0000028
10000	.0005100	.0000543	.0004991	.0000505	.0000109	.0000038
11000	.0005500	.0000400	.0005343	.0000352	.0000157	.0000048
12000	.0006414	.0000914	.0006157	.0000814	.0000257	.0000100
13000	.0007100	.0000686	.0006800	.0000643	.0000300	.0000043
14000	.0007700	.0000600	.0007343	.0000543	.0000357	.0000057
15000	.0008557	.0000857	.0008080	.0000737	.0000477	.0000120
16000	.0009243	.0000686	.0008714	.0000634	.0000529	.0000052
17000	.0010014	.0000771	.0009371	.0000657	.0000643	.0000114
18000	.0010900	.0000886	.0009886	.0000515	.0001014	.0000371
19000	.0012271	.0001371	.0010800	.0000914	.0001471	.0000457
20000	.0013586	.0001315	.0011572	.0000772	.0002014	.0000543
21000	.0015386	.0001800	.0012486	.0000914	.0002900	.0000886
22000	.0017043	.0001657	.0013057	.0000571	.0003986	.0001086
23000	.0019529	.0002486	.0014000	.0000943	.0005529	.0001543
24000	.0022786	.0003257	.0015257	.0001257	.0007529	.0002000
25000	.0026037	.0003251	.0015194	—.0000063	.0010843	.0003314
26000	.0032186	.0006149	—	—	—	—

TABLE *showing the extension, restoration and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 in. long and 1.382 in. diameter, taken from near the surface of the bore of triplicate 10-inch Columbiad, No. 335, cast solid, at the Fort Pitt Foundry, in 1857.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.0000600	—	.0000600	—	—	—
2000	.0001343	.0000743	.0001343	.0000743	—	—
3000	.0002057	.0000714	.0002000	.0000657	.0000057	—
4000	.0002657	.0000600	.0002543	.0000543	.0000114	.0000057
5000	.0003257	.0000600	.0003114	.0000571	.0000143	.0000029
6000	.0003800	.0000543	.0003543	.0000429	.0000257	.0000114
7000	.0004514	.0000714	.0004143	.0000600	.0000371	.0000114
8000	.0005314	.0000800	.0004771	.0000628	.0000543	.0000172
9000	.0006171	.0000857	.0005457	.0000686	.0000714	.0000171
10000	.0007114	.0000943	.0006171	.0000714	.0000943	.0000229
11000	.0008114	.0001000	.0006885	.0000714	.0001229	.0000286
12000	.0009229	.0001115	.0007600	.0000715	.0001629	.0000400
13000	.0010743	.0001514	.0008371	.0000771	.0002372	.0000743
14000	.0012429	.0001686	.0009458	.0001087	.0002971	.0000599
15000	.0014086	.0001657	.0010229	.0000771	.0003857	.0000886
16000	.0016371	.0002285	.0011114	.0000885	.0005257	.0001400
17000	.0019571	.0003200	.0012314	.0001200	.0007257	.0002000
18000	.0023143	.0003572	.0013086	.0000772	.0010057	.0002800
19000	.0028257	.0005114	.0014143	.0001057	.0014114	.0004057

TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder, 35 in. long and 1.382 in. diameter, taken from near the exterior surface of triplicate 10-inch Columbiad, No. 335, cast solid, at the Fort Pitt Foundry, in 1857.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.0000429	—	.0000415	—	.0000014	—
2000	.0001086	.0000657	.0001057	.0000642	.0000029	.0000015
3000	.0001714	.0000628	.0001657	.0000600	.0000057	.0000028
4000	.0002343	.0000629	.0002257	.0000600	.0000086	.0000029
5000	.0002943	.0000600	.0002814	.0000557	.0000129	.0000043
6000	.0003543	.0000600	.0003372	.0000558	.0000171	.0000042
7000	.0004200	.0000657	.0003971	.0000599	.0000229	.0000058
8000	.0004886	.0000686	.0004600	.0000629	.0000286	.0000057
9000	.0005571	.0000685	.0005200	.0000600	.0000371	.0000085
10000	.0006314	.0000743	.0005828	.0000628	.0000486	.0000115
11000	.0007029	.0000715	.0006400	.0000572	.0000629	.0000143
12000	.0007943	.0000914	.0007143	.0000743	.0000800	.0000171
13000	.0008943	.0001000	.0007857	.0000714	.0001086	.0000286
14000	.0010114	.0001171	.0008571	.0000714	.0001543	.0000457
15000	.0011428	.0001314	.0009299	.0000728	.0002129	.0000586
16000	.0012714	.0001286	.0009600	.0000301	.0003114	.0000985
17000	.0014914	.0002200	.0010000	.0000400	.0004914	.0001800
18000	.0018114	.0003200	.0011514	.0001514	.0006600	.0001686
19000	.0022772	.0004658	.0012144	.0000630	.0010628	.0004028
20000	.0029000	.0006228	.0013000	.0000856	.0016000	.0005372
21000	.0033657	.0004657	Specimen broke before the permanent set could be measured.			

For compressibility, bars contiguous, in the guns, to those for extensibility, were tested; the measuring apparatus was the same, and the bars were similarly prepared in all respects, except that they were only ten inches long between the collars.

The results thus obtained are recorded in the following tables :—

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TABLE *showing the compression, restoration and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder* 10 *inches long and* 1.382 *inches diameter, taken from near the surface of the bore of triplicate* 10-*inch Columbiad, No.* 983, *cast solid, at the West Point Foundry, in* 1857.

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.000100	—	—	—	—	—
2000	.000240	.000140	—	—	—	—
3000	.000310	.000070	.000300	—	.000010	—
4000	.000380	.000070	.000340	.000040	.000040	.000030
5000	.000435	.000055	.000375	.000035	.000060	.000020
6000	.000505	.000070	.000440	.000065	.000065	.000005
7000	.000540	.000035	.000475	.000035	.000065	.000000
8000	.000625	.000085	.000555	.000080	.000070	.000005
9000	.000670	.000045	.000540	—.000015	.000130	.000060
10000	.000780	.000110	.000640	+.000100	.000140	.000010
11000	.000850	.000070	.000700	.000060	.000150	.000010
12000	.000890	.000040	.000730	.000030	.000160	.000010
13000	.000965	.000075	.000790	.000060	.000175	.000015
14000	.001010	.000045	.000800	.000010	.000210	.000035
15000	.001055	.000045	.000835	.000035	.000220	.000010
16000	.001095	.000040	.000865	.000030	.000230	.000010
17000	.001240	.000145	.000990	.000125	.000250	.000020
18000	.001295	.000055	.001015	.000025	.000280	.000030
19000	.001345	.000050	.001055	.000040	.000290	.000010
20000	.001430	.000085	.001120	.000065	.000310	.000020
21000	.001490	.000060	.001150	.000030	.000340	.000030
22000	.001570	.000080	.001200	.000050	.000370	.000030
23000	.001620	.000050	.001230	.000030	.000390	.000020
24000	.001720	.000100	.001290	.000060	.000430	.000040
25000	.001790	.000070	.001320	.000030	.000470	.000040
26000	.001880	.000090	.001380	.000060	.000500	.000030
27000	.001955	.000075	.001415	.000035	.000540	.000040
28000	.002040	.000085	.001455	.000040	.000585	.000045
29000	.002105	.000065	.001485	.000030	.000620	.000035
30000	.002250	.000145	.001560	.000075	.000690	.000070

TABLE *showing the compression, restoration and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder* 10 *inches long and* 1.382 *in. diameter, taken from near the exterior surface of triplicate* 10-*inch Columbiad, No.* 983, *cast solid, at the West Point Foundry, in* 1857.

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.000090	—	·000090	—	—	—
2000	.000170	.000080	.000170	.000080	—	—
3000	.000255	.000085	·000250	.000080	.000005	—
4000	.000320	.000065	.000305	.000055	.000015	.000010
5000	.000385	.000065	.000360	.000055	.000025	.000010
6000	.000455	.000070	.000425	.000065	.000030	.000005
7000	.000505	.000050	.000470	.000045	.000035	.000005
8000	.000575	.000070	.000530	.000060	.000045	.000010
9000	.000645	.000070	.000590	.000060	.000055	.000010
10000	.000705	.000060	.000635	.000045	.000070	.000015
11000	.000790	.000085	.000680	.000045	.000110	.000040
12000	.000845	.000055	.000725	.000045	.000120	.000010
13000	.000905	.000060	.000775	.000050	.000130	.000010
14000	.000955	.000050	.000810	.000035	.000145	.000015
15000	.001035	.000080	.000865	.000055	.000170	.000025
16000	.001090	.000055	.000905	.000040	.000185	.000015
17000	.001165	.000075	.000955	.000050	.000210	.000025
18000	.001250	.000085	.001015	.000060	.000235	.000025
19000	.001335	.000085	.001065	.000050	.000270	.000035
20000	.001395	.000060	.001095	.000030	.000300	.000030
21000	.001485	.000090	.001150	.000055	.000335	.000035
22000	.001555	.000070	.001190	.000040	.000365	.000030
23000	.001655	.000100	.001250	.000060	.000405	.000040
24000	.001750	.000095	.001295	.000045	.000455	.000050
25000	.001825	.000075	.001330	.000035	.000495	.000040
26000	.001940	.000115	.001385	.000055	.000555	.000060
27000	.002050	.000110	.001440	.000055	.000610	.000055
28000	.002145	.000095	.001475	.000035	.000670	.000060
29000	.002250	.000105	.001515	.000040	.000735	.000065
30000	.002380	.000130	.001560	.000045	.000820	.000085

TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder* 10 *in. long and* 1.382 *in. diameter, taken from near the surface of the bore of triplicate* 10-*inch Columbiad, No.* 335, *cast solid, at the Fort Pitt Foundry, in* 1857.

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.000145	—	.000145	—	—	—
2000	.000225	.000080	.000225	.000080	—	—
3000	.000305	.000080	.000300	.000075	.000005	—
4000	.000375	.000070	.000360	.000060	.000015	.000010
5000	.000465	.000090	.000440	.000080	.000025	.000010
6000	.000530	.000065	.000485	.000045	.000045	.000020
7000	.000615	.000085	.000560	.000075	.000055	.000010
8000	.000695	.000080	.000610	.000050	.000085	.000030
9000	.000755	.000060	.000660	.000050	.000095	.000010
10000	.000825	.000070	.000695	.000035	.000130	.000035
11000	.000895	.000070	.000730	.000035	.000165	.000035
12000	.000985	.000090	.000800	.000070	.000185	.000020
13000	.001055	.000070	.000850	.000050	.000205	.000020
14000	.001125	.000070	.000875	.000025	.000250	.000045
15000	.001220	.000095	.000955	.000080	.000265	.000015
16000	.001305	.000085	.001000	.000045	.000305	.000040
17000	.001415	.000110	.001065	.000065	.000350	.000045
18000	.001510	.000095	.001115	.000050	.000395	.000045
19000	.001595	.000085	.001165	.000050	.000430	.000035
20000	.001710	.000115	.001215	.000050	.000495	.000065
21000	.001830	.000120	.001275	.000060	.000555	.000060
22000	.001955	.000125	.001315	.000040	.000640	.000085
23000	.002090	.000135	.001370	.000055	.000720	.000080
24000	.002240	.000150	.001430	.000060	.000810	.000090
25000	.002380	.000140	.001475	.000045	.000905	.000095
26000	.002540	.000160	.001475	.000000	.001065	.000160
27000	.002780	.000240	.001565	.000090	.001215	.000150
28000	.003010	.000230	.001655	.000090	.001355	.000140
29000	.003295	.000285	.001770	.000115	.001525	.000170
30000	.003490	.000195	.001720	—.000050	.001770	.000240

TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 10 inches long and 1.382 in. diameter, taken from near the exterior surface of triplicate 10-inch Columbiad, No. 355, cast solid, at the Fort Pitt Foundry, in 1857.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.000075	—	.000075	—	—	—
2000	.000155	.000080	.000150	.000075	.000005	—
3000	.000205	.000050	.000195	.000045	.000010	.000005
4000	.000265	.000060	.000250	.000055	.000015	.000005
5000	.000355	.000090	.000335	.000085	.000020	.000005
6000	.000465	.000110	.000430	.000095	.000035	.000015
7000	.000545	.000080	.000490	.000060	.000055	.000020
8000	.000625	.000080	.000555	.000065	.000070	.000015
9000	.000685	.000060	.000600	.000045	.000085	.000015
10000	.000770	.000085	.000665	.000065	.000105	.000020
11000	.000835	.000065	.000705	.000040	.000130	.000025
12000	.000895	.000060	.000745	.000040	.000150	.000020
13000	.000970	.000075	.000800	.000055	.000170	.000020
14000	.001055	.000085	.000855	.000055	.000200	.000030
15000	.001140	.000085	.000905	.000050	.000235	.000035
16000	.001230	.000090	.000960	.000055	.000270	.000035
17000	.001310	.000080	.000995	.000035	.000315	.000045
18000	.001385	.000075	.001030	.000035	.000355	.000040
19000	.001485	.000100	.001085	.000055	.000400	.000045
20000	.001575	.000090	.001135	.000050	.000440	.000040
21000	.001690	.000115	.001175	.000040	.000515	.000075
22000	.001815	.000125	.001225	.000050	.000590	.000075
23000	.001935	.000120	.001275	.000050	.000660	.000070
24000	.002060	.000125	.001330	.000055	.000730	.000070
25000	.002200	.000140	.001360	.000030	.000840	.000110
26000	.002350	.000150	.001385	.000025	.000965	.000125
27000	.002560	.000210	.001455	.000070	.001105	.000140
28000	.002765	.000205	.001480	.000025	.001285	.000180
29000	.003035	.000270	.001505	.000025	.001530	.000245
30000	.003410	.000375	.001520	.000015	.001890	.000360

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TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the repeated applications of* 15000 *pounds per square inch, — about three-fourths of its ultimate strength, — upon a solid cylinder,* 35 *in. long and* 1.382 *in. diameter, taken from near the exterior surface of triplicate* 10-*inch Columbiad, No.* 335, *cast solid, at the Fort Pitt Foundry, in* 1857.

Number of repe-titions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1	.001278	—	.000971	—	.000307	—
2	.001291	.000013	.000965	—.000006	.000226	.000019
3	.001304	.000013	.000968	+ 000003	.000336	.000010
4	.001320	.000016	.000977	.000009	.000343	.000007
5	.001327	.000007	.000978	.000001	.000349	.000006
6	.001337	.000010	.000978	.000000	.000359	.000010
7	.001346	.000009	.000980	.000002	.000366	.000007
8	.001349	.000003	.000976	—.000004	.000373	.000007
9	.001354	.000005	.000975	—.000001	.000379	.000006
10	.001357	.000003	.000969	—.000006	.000388	.000009
11	.001364	.000007	.000970	+.000001	.000394	.000006
12	.001368	.000004	.000971	.000001	.000397	.000003
13	.001374	.000006	.000974	.000003	.000400	.000003
14	.001377	.000003	.000974	.000000	.000403	.000003
15	.001380	.000003	.000976	.000002	.000404	.000001
16	.001381	.000001	.000975	—.000001	.000406	.000002
17	.001383	.000002	.000976	+.000001	.000407	.000001
27	.001389	.000006	.000976	.000000	.000413	.000006
37	.001403	.000014	.000982	.000006	.000421	.000008
*47	.001471	.000068	.000985	.000003	.000486	.000065
57	.001480	.000009	.000986	.000001	.000494	.000008
67	.001487	.000007	.000984	—.000002	.000503	.000009
77	.001491	.000004	.000982	—.000002	.000509	.000006
87	.001503	.000012	.000983	+.000001	.000520	.000011
100	.001510	.000007	.000984	.000001	.000526	.000006
110	.001513	.000003	.000984	.000000	.000529	.000003
120	.001516	:000003	.000985	.000001	.000531	.000002
130	.001517	.000001	.000981	—.000004	.000536	.000005
140	.001527	.000010	.000984	+.000003	.000543	.000007
150	.001530	.000003	.000977	—.000007	.000553	.000010
160	.001533	.000003	.000980	+.000003	.000553	.000000
200	.001533	.000000	.000977	—.000003	.000556	.000003
250	.001537	.000004	.000977	.000000	.000560	.000004

Specimen remained free from strain forty hours, in which time its permanent set diminished .00210, and its extension under 15000 lbs. diminished .00080.

* For this series, about 500 lbs. too much was once applied.

TABLE *of repetition of strain*—Continued.

Number of repetitions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
300	.001528	—	.000998	—	.000530	—
350	.001545	.000017	.000999	.000001	.000546	.000016
400	.001556	.000011	.001005	.000006	.000551	.000005
450	.001556	.000000	.001003	—.000002	.000553	.000002
500	.001624	.000068	.001018	+.000015	.000606	.000053
550	.001646	.000022	.001032	.000014	.000614	.000008
600	.001651	.000005	.001031	—.000001	.000620	.000006
625	.001663	.000012	.001017	—.000014	.000646	.000026
After remaining free from strain 30 days, permanent set diminished .00130, and extension under same force as above, .00100.						
650	.001647	—	.001011	—	.000636	—
700	.001666	.000019	.001015	.000004	.000651	.000015
780	.001687	.000021	.001021	.000006	.000666	.000015
After 29 days rest, free from strain, set diminished .00340, and extension under same strain as above, .00295.						
800	.001617	—	.001037	—	.000580	—
900	.001640	.000023	.001046	.000009	.000594	.000014
1000	.001668	.000028	.001037	—.000009	.000631	.000037
1114	.001737	.000069	.001037	.000000	.000700	.000069
1214	.001785	.000048	.001039	+.000002	.000746	.000046
*1325	.002077	.000292	.001049	.000010	.001028	.000282
1436	.002103	.000026	.001060	.000011	.001043	.000015
1536	.002123	.000020	.001063	.000003*	.001060	.000017
1736	.002297	.000174	.001139	.000076	.001158	.000098
1800	.002297	.000000	.001106	.000033	.001191	.000033
After 26 days rest, set diminished .00290, and extension under same strain as above, .00280.						
1892	.002305	—	.001128	—	.001177	—
Broke at the 1956th repetition.						
Mean,	—	—	.001003	—	—	—

* About 1000 lbs. too much was once applied in this series.

Deductions and Conclusions from the Foregoing Results.

The most interesting features observable in the results recorded in the fore-going tables, and more clearly shown by the curves constructed from them, (see Plates 12 to 23, inclusive,) are, —

1st. The very marked difference in the extension due to equal increments of force, when the total force is small, and when it nearly approaches that of rupture.

2d. The irregularity of increase in these differences; and

3d. The excess of compression over the extension, due to the same force, when that force is comparatively small, and the excess of the extension over the compression, due to the same force, when that force nearly approaches the ultimate tensile strength of the specimen.

If the specimen were perfectly homogeneous throughout, in both structure and properties, as if it were a single crystal, then the changes which it would undergo, from the application of a regularly increasing force, would be in accordance with some regular law; and, if the experiments were accurately made, the results would be in strict accordance with that law, and all the points of the curve expressive of the experimental results would fall upon the curve expressive of the law.

The measuring apparatus used in these experiments afforded the means of measuring any changes of length in the specimens for extension, amounting to the .000003 part of an inch per inch in length, and any amounting to the .00001 part of an inch per inch in length, in those for compression.

The irregularities exhibited by the columns of first differences being so very much greater than either of these quantities, cannot be attributed to errors of measurement, and are believed to be mainly due to the inherent properties of the specimens themselves.

These specimens are composed, not of a single crystal, but of groups of crystals, the planes of whose principal faces occupy every conceivable position with reference to the direction of the straining force.

Those crystals whose principal faces are perpendicular to the direction of the straining force, are susceptible of the minimum extension or compression in that direction, and must therefore under a force of extension be the first to rupture; while those whose principal faces are parallel to the direction of that force, will have the maximum extensibility, and will be the last to rupture;

PLATE XII.

Curves expressive of extensibility, compressibility and corresponding set,
of inner specimen from West Point Gun N.º 983.
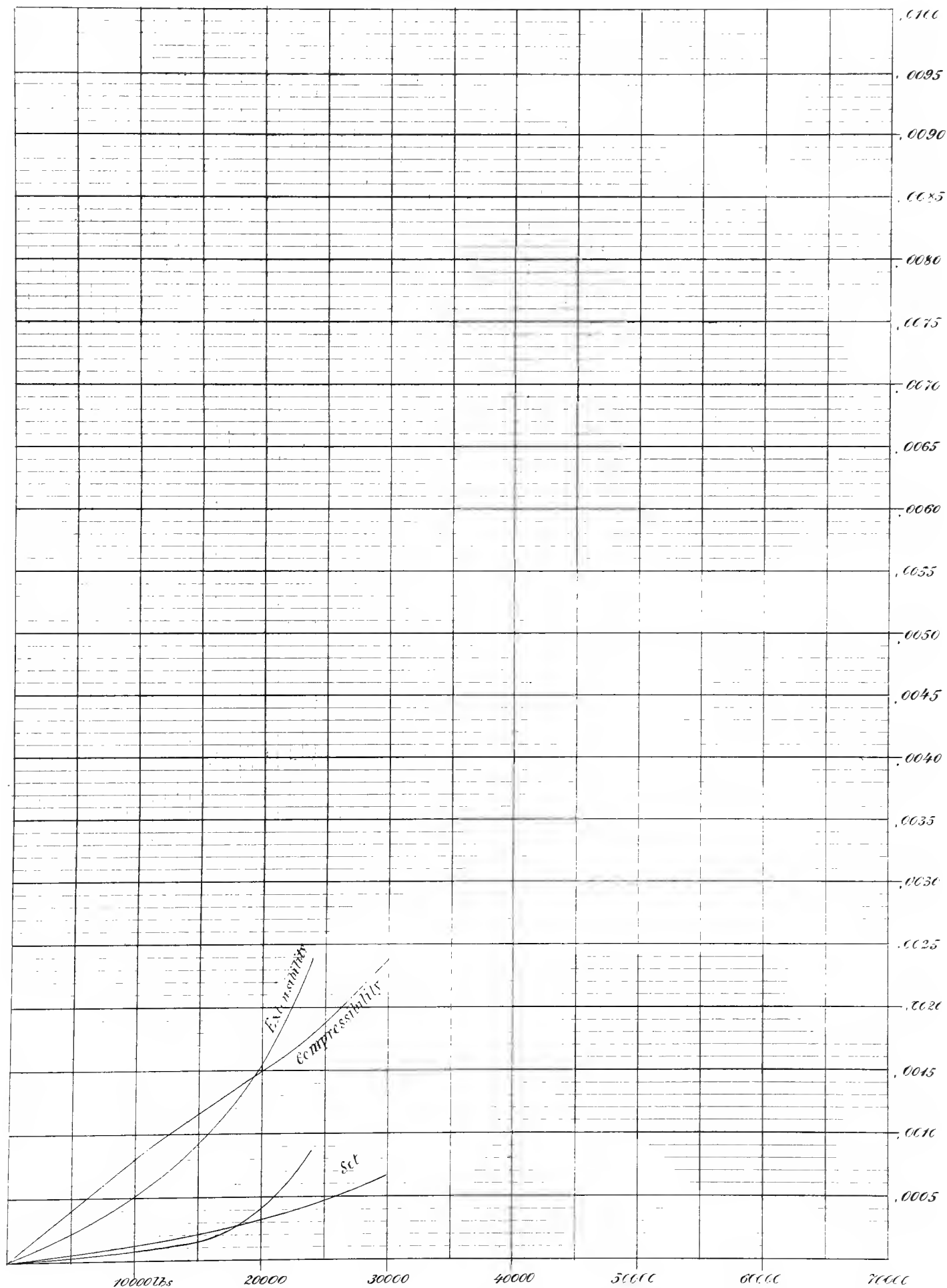
Extensibility

Compressibility

Set

.0100
.0095
.0090
.0085
.0080
.0075
.0070
.0065
.0060
.0055
.0050
.0045
.0040
.0035
.0030
.0025
.0020
.0015
.0010
.0005

10000 lbs   20000   30000   40000   50000   60000   70000

PLATE XIII.

Curves expressive of extensibility, compressibility and corresponding set,
of outer specimen from West Point Gun N.º 983.

PLATE XIV.
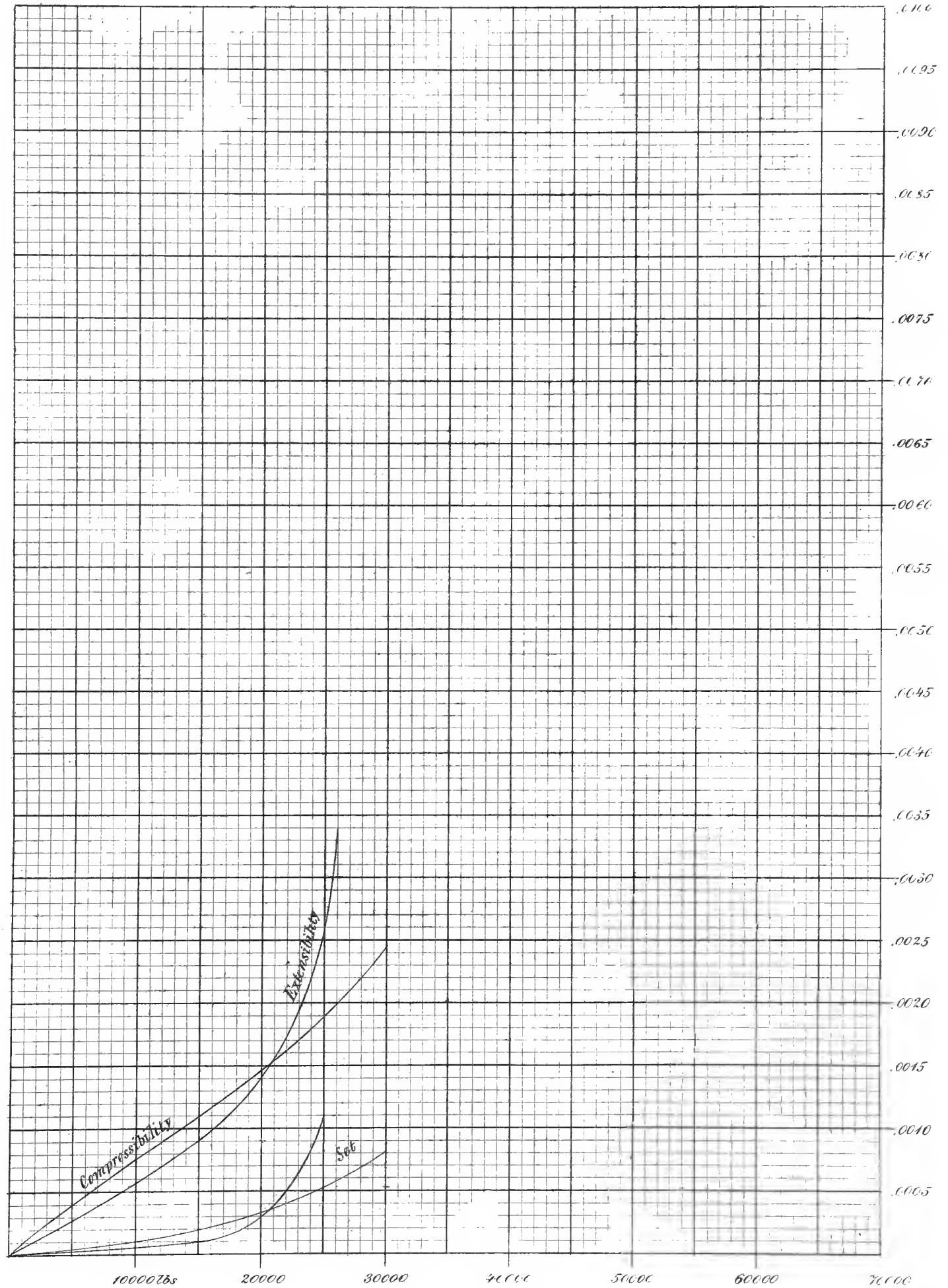
Curves expressive of extensibility, compressibility and of corresponding set
of inner specimen from Fort Pitt Gun N.º 335

Extensibility

Compressibility

Set

.0100
.0095
.0090
.0085
.0080
.0075
.0070
.0065
.0060
.0055
.0050
.0045
.0040
.0035
.0030
.0025
.0020
.0015
.0010
.0005

10000 lbs   20000   30000   40000   50000   60000   70000

PLATE XV.

Curves expressive of extensibility, compressibility and corresponding set of outer specimen from Fort Pitt Gun N°535

PLATE XVI.

Comparing extensibility and set, of inner and outer specimens from West Point Gun N° 983.

PLATE XVII

Comparing compressibility and set of inner and outer specimens from West Point Gun N°983.

PLATE XVIII

Comparing extensibility and set of inner and outer specimens from Fort Pitt
Gun N.º 335.

PLATE XIX

Comparing compressibility and set of inner and outer specimens from
Fort Pitt Gun N:335

PLATE XX

Comparing extensibility and set of inner specimens from West Point Gun N⁰ 983 and Fort Pitt Gun N⁰ 335.

Comparing extensibility and set of inner specimens from West Point Gun N⁰ 983 and Fort Pitt Gun N⁰ 335.

PLATE XXI.

Comparing extensibility and set of outer specimens from West Point
Gun N.º 983 and Fort Pitt Gun N.º 335

PLATE XXII.

Comparing compressibility and set, of inner specimens from West Point
Gun N.º 983 and Fort Pitt Gun N.º 335.

Fort Pitt

West Point

Pitt

Fort

West Point

10000 lbs.   20000   30000   40000   50000   60000   70000

.0100
.0195
.0190
.0185
.0180
.0175
.0170
.0165
.0160
.0155
.0150
.0145
.0140
.0135
.0130
.0125
.0120
.0115
.0110
.0105

PLATE XXIII.

Comparing compressibility and set of outer specimens from West Point
Gun Nº 983 and Fort Pitt Gun Nº 335

those whose principal faces are oblique to the direction of the force, being intermediate, in extensibility, and times of rupture, between these limits.

It would therefore appear that rupture, from a force of extension, in a specimen thus constituted, ought to take place in detail, group after group of crystals giving way, and throwing the strain upon those that are susceptible of greater extension, and thus causing irregularity in the increments of extension, due to equal and regular increments of force.

And the increments of extension, due to equal increments of force, ought to be less, while that force is small, and while it is rupturing those groups of crystals which have the minimum extensibility, than when it is larger, and when it is rupturing those groups which have greater extensibility; and finally, those increments should be greater when the force is rupturing those groups which are susceptible of the maximum extension.

Compression.

Under a force of compression, the foregoing results indicate that motion first takes place among those crystals whose principal faces are parallel to the direction of the force.

Equal increments of force ought consequently to give greater increments of compression while the force is so small as to put in motion only crystals thus situated, than when it is greater, and is beginning to bring into action those whose principal faces are perpendicular to the direction of the force.

And the minimum increment of compression, due to a given increment of force, ought to occur at the time the resistance offered by those crystals, whose principal faces are perpendicular to the direction of the force, is being overcome; and as these crystals begin to yield, by being broken up, as it is believed, the increments of compression begin to increase, and continue so to do until the specimen gives way, and rupture ensues.

The curve expressive of these properties in the specimens, and of the experimental results, would be first concave and then convex, towards the axis of abscissa, when the abscissa of the curve represents the force, and the ordinates the corresponding compressions in the specimen.

The super-position of the curves of compression upon those of extension shows very clearly that, under a transverse strain, the neutral axis, in a specimen of the same quality of iron as that from which the foregoing results were obtained, would, at first, be nearest the extended or convex face of the

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specimen, and would, as the force would increase, be further and further removed from that face, and would, when the force would equal about three-fourths of that of rupture, be at the middle of the depth of the specimen; and for all forces greater than this, it would be nearest the concave or compressed face of the specimen.

The point of intersection of the curve of extension with that of compression, the origin of co-ordinates being the same for both, of any specimen, gives the force which will place the neutral axis in the middle of the depth of the specimen.

Intermittent Force of Constant Intensity.

The most interesting point in the results obtained from subjecting a specimen of the same quality of iron as that from which the other tabulated results were obtained, to a repetition of a strain equal to about three-fourths of its breaking weight, is the fact that at every interval of rest, of any considerable time, the permanent set, and the extension due to the last previous application of the force, diminished.

And in some instances it required some fifty repetitions to bring up the extension and set to the same points where they had been at the beginning of the period of rest; thus indicating clearly that the specimen was partially restored, by the interval of rest, from the injury which it had previously received; and that it endured a greater number of repetitions, owing to the intervals of rest, than it would have done had the repetitions succeeded each other continuously, and at short intervals of time.

These results would therefore lead to the belief that a gun will endure a greater number of rounds if fired at intervals, with periods of rest of considerable length intervening, than if fired continuously.

The indications of a single result ought not, however, to be regarded as conclusive; and it is believed to be highly important that this experiment should be repeated, so as to leave no doubt as to the conclusions to be drawn from the results.

Another feature of this experiment is, that the ultimate extension is less than it was in the corresponding specimen which was broken by adding 1000 lbs. to the force at each repetition; from which it is concluded that each repetition diminishes the ultimate extensibility of the specimen, and that any molecular disturbance diminishes the quantity of work which the specimen is capable of performing, or the *work done,* in effecting its rupture.

Capacity for Work.

The term *work done* does not clearly convey the idea intended here, and has, besides, a technical meaning, signifying the product arising from multiplying the intensity of a force by the distance passed over by its point of application.

Thus the *work done* in raising a weight through a given height is, in Mechanics, expressed by the product of the weight by the height to which it is raised.

The term *capacity for work* is believed to be more appropriate, and is intended to signify ability to resist sudden applications of force; it is analytically expressed by the sum of the products arising from multiplying each successive increment of force, per unit of section, by the total corresponding extension per unit of length; and is geometrically expressed by the area bounded by the curve expressive of the experimental results of any specimen, the axis of abscissa, and the ordinate of that point of this curve, corresponding to the force of rupture of the specimen; or when the specimen is broken by a single application of force, and only the ultimate extension is measured, then the *capacity for work* would be approximately expressed by half the product of this force by the ultimate extension.

And although this is not so accurate a measure of the *capacity for work* as that obtained by the successive application of forces of regularly increasing intensity with the measurement of the corresponding extensions, yet it serves very well as a means of comparing the *capacity for work* of one specimen with that of another; is more easily obtained, and would, for a material in which equal increments of force give equal increments of extension, accurately express its *capacity for work*.

The *capacity for work* is a compound quality, being composed of the tensile strength, and the extensibility of the specimen when it is subjected to a sudden force of extension only; but when the specimen is subjected to a transverse strain, or to the action of a central bursting force, then its capacity for work is composed of the two above named qualities, together with that of incompressibility.

This last named quality having the effect, in transverse resistance, to place the neutral axis nearer to the compressed face of the specimen, and thus to increase the area of section which is subjected to a force of extension, and to

increase the distance from the neutral axis at which the resistance offered by this area acts, and consequently to increase the amount of resistance which the specimen is capable of offering.

And in the resistance which a gun or other hollow cylinder offers to a central bursting force, the more incompressible the metal, the more perfectly will the force exerted upon the inner surface be transmitted to the surrounding and exterior portions, and the greater will be the tangential resistance of which the gun or cylinder will be capable; and if only a portion of the interior length of the gun or cylinder be subjected to the action of the central force, then the greater will also be the transverse resistance developed.

This compound quality furnishes the best known standard of excellence for a material intended to resist a single sudden application of force; such as the shock of a falling body, or a single discharge of great bursting tendency, when made into a gun, or in resisting the force of the projecting charge, when made into shells.

And in metal intended for shells, its capacity for work should consist rather of tensile strength and incompressibility than of extensibility; but in metal intended for guns, machinery, or any other purpose requiring it to sustain a great number of repetitions of sudden applications of forces, of nearly constant intensity, then the *work due to elasticity* is of greater importance.

The term *work due to elasticity* is intended to signify ability to resist repetitions of forces of less intensity than that which would produce rupture by a single application; and is expressed by the sum of the products arising from multiplying the intensity of each repetition of force, per unit of section, by half the corresponding total restoration, per unit of length, which the specimen undergoes on being entirely relieved from strain.

The foregoing results also indicate that the application of any force, however small it may be, effects a certain amount of permanent injury to the specimen to which it is applied, or that there is no such property in cast iron as perfect elasticity, no matter how small may be the molecular disturbance.

The production of a permanent set of measurable magnitude, by a force of 1000 lbs. per square inch, seems to leave no doubt that a permanent set is actually produced by a much less force, though our present means of measurement are incapable of detecting it.

All the foregoing results were obtained from specimens which had been subjected to previous strain and vibrations, being taken from fragments of broken guns.

It is believed that more reliable results would be obtained by experimenting on specimens which had been subjected to no previous strains, nor molecular disturbances.

For it is impossible to reason back to what would have been either the capacity for work, or the work due to elasticity of an unstrained specimen, by knowing to what extent these properties were possessed by that specimen, after it had been subjected to both strains and vibrations of unknown intensity and number.

And although it is interesting to know to what extent these properties are possessed by the fragments of worn-out guns, yet it would be of far greater practical utility and importance to know the value of these properties in the new untried gun.

And since it is impossible to study the properties and conditions as to strain, &c., of the iron after it has been made into guns, and before they are broken, it is believed to be of the utmost importance that before any lot of iron shall be pronounced fit to be cast into guns, either a sample gun, or a cylinder of equal diameter, and at least half the length of the gun, should be cast, and test specimens cut from it, and tested.

The test gun or cylinder should be of the same diameter as the guns to be made, and should be made under the same circumstances which are to attend the preparation of the iron for, and the casting and cooling of, the guns themselves.

Specimens thus obtained would afford reliable results; and if accompanied by the powder proof, with service charges, of guns cast at the same heat, these results would become standards with which to compare other lots of iron, or other guns, and thus to determine beforehand, with some degree of certainty, the number of rounds which a gun will stand.

And in advance or anticipation of the powder proof for that purpose, it is believed that a fair approximation to the difference in endurance of guns due to different bursting tendencies at each discharge, might be made by breaking a series of specimens cut from the same casting, by a series of repetitions of strains bearing certain definite relations to the tensile strength of the specimens. Say three specimens, by repetitions of a strain equal to

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half of their tensile strength, three by repetitions of a strain $= \frac{5}{8}$, three by repetitions of a strain $= \frac{3}{4}$, and three by repetitions of a strain $= \frac{7}{8}$ of their tensile strength.

Then, if we knew the bursting tendency to which a gun of the same quality of iron is subjected at each discharge, it would seem to warrant the prediction that the gun would endure the same number of repetitions as the specimen, of a force bearing the same ratio to its ultimate strength.

This would undoubtedly be true if the repetitions were made in the same manner, and the specimens subjected to the same number and extent of vibrations, at each repetition, as the iron in the gun, and the gun were free from previous strain.

The difference in endurance due to the difference in mode of application and effects of vibration, at each repetition, could be determined only by accompanying the proof of the test specimens with the powder proof of the guns.

Of the Absolute Pressure of Gas in the Bore of a Gun.

With a view to determine the absolute pressure exerted upon the bore of a 42-pdr. gun in firing, under various circumstances, the following experiments were made, viz. : —

A 42-pdr. gun was pierced through the cascabel, along the axis, and at intervals of two calibres along its side and perpendicular (except that nearest the muzzle) to its exterior surface, with holes .38 in. in diameter, and extending through to the bore. Concentric with these holes were bored others 1.5 in. in diameter, and 1.5 in. deep.

These holes were tapped, and the housing which contained the indenting tool and the copper specimen to be indented, was screwed into one of them, when in use, the others being filled with plugs, tightly screwed in. The diameter of the indenting piston, on the the inner end of which the pressure of the gas was exerted, was 0.368 in.

The following Plates show a section, through the axis, and a side elevation of the indenting apparatus. The indenting tool had a snug *working fit* in the housing.

The hole in the housing shown at (*c*) and the recess around the stem of the indenting tool which it enters, were made for the purpose of letting out any

PLATE XXIV

Fig 1

C   Indenting Apparatus

g

Indenting tool

Fig 4

Fig. 2

Fig 3

Indenting tool

Copper

Fig. 2

g   S
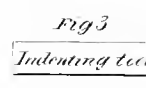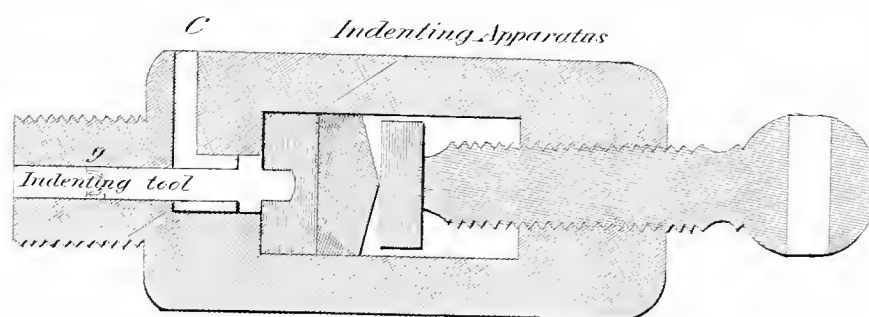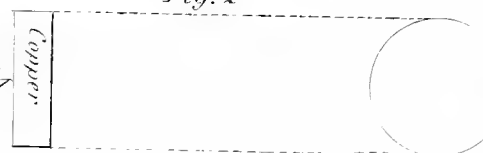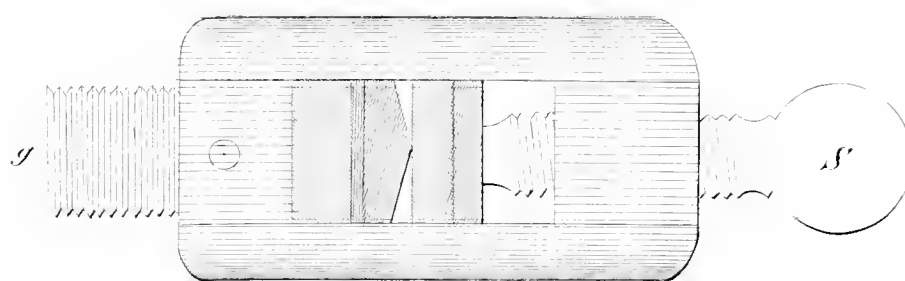
gas that might pass the piston, and thus prevent its acting against the shoulder of the indenting tool, and for this purpose it answered very well.

The mode of determining pressures by this apparatus is as follows : —

The shank, or piston, of the indenting tool, and the hole in the housing into which it is inserted for use, are well cleaned and oiled, and the indenting tool inserted into the housing, which is then screwed into the gun, and a disc of soft copper placed on the point of the indenting tool, the disc being held in position by the screw (s) acting either upon a second copper disc, or upon a piece of iron having a plane surface next the disc to be indented.

The pressure exerted upon the inner end of the indenting piston forces the point of the indenting tool into the copper disc when the gun is fired. This disc is then removed to the testing machine, and the pressure required to produce an equal indentation with the same tool, in the same disc, or one from the same bar of copper, is accurately weighed ; then knowing the area of a cross section of the indenting piston, the pressure per square inch is calculated. For the purpose of getting greater accuracy of results, the indenting point is very broad and thin, so as to make a very *long* cut as compared with its breadth and depth.

With the tool used in these experiments, a difference of pressure of 25 lbs. was distinctly perceptible, when added to a pressure of 3000 lbs. on the indenting tool, and corresponding to a pressure of about 30000 lbs. per square inch in the gun, or to an error of less than 250 lbs. in 30000 lbs.

So that the indications of this instrument may be *safely* regarded as approximating to within 1000 lbs. of the true pressure, even for the greatest pressures exerted, and much nearer for the smaller pressures.

This method of determining the pressure of gas in the bore of a gun, and a modification of it, involving the use of a spring in lieu of the indenting tool and specimen, was suggested by me to Major W. Wade as early as 1851, who thought well of it. He, however, left the employ of the Department about that time, and I never had an opportunity of applying it till in these experiments, when it was first applied to the experimental 42-pdr. gun.

This apparatus was attached to the breech of the 42-pdr. gun when firing the proof charges, and gave the following pressures per square inch : —

Pressure per Square Inch due to Proof Charges in the 42-pdr. Gun.

21 lbs. powder, 2 shot and 1 wad gave a pressure at the bottom

of the bore, ... = 64510 lbs.

14 lbs. powder, 2 shot and 1 wad gave a pressure at the bottom

of the bore, ... = 55622 lbs.

21 lbs. powder, 1 shot and 1 wad gave pressure, . . = 47785 lbs.

Preliminary Trials with Accelerating Cartridges.

Two rounds were fired with 9 lbs. 14 oz. cartridges and a 43-lb. shot, giving a mean pressure per square in. at the bottom of the bore = 4395 lbs., with a mean recoil = 14° 54´.

One round fired with 19 lbs. 12 oz. cartridge and a 43-lb. shot gave a recoil over 30° 00´, which was the limit of the arc, and cut the lead indenting specimen through, so that the pressure was not determined.

With Grained Powder.

One round was then fired with 10 lbs. *grained powder*, and same shot, with a recoil = 22° 34´, and indicated greater pressure than that due to 19 lbs. 12 oz. accelerating cartridge.

5 lbs. powder gave pressure = 17000 lbs., and recoil = 15° 37´.

4 lbs. 6½ oz. powder gave pressure = 16983 lbs., and recoil = 14° 02´.

Pressure of Gas at different points along the Bore.

For the purpose of determining the pressure at different distances from the bottom of the bore, two series were fired, one with 10 lbs. grained powder and the other with 13 lbs. accelerating cartridges, same weight of shot and sabot in both series, and charges accurately weighed, powder for grained cartridges having been mixed.

NUMBER OF FIRES.		Distance from the bottom of bore.	PRESSURE PER INCH.		RECOIL.	
Accelerating.	Grained.		Accelerating.	Grained.	Accelerating.	Grained.
3	3	At bottom.	10989	41289	22° 24´	22° 58´
3	3	2 calibres.	26001	57512	24 21	22 56
3	3	4 "	12457	14103	22 57	22 59
3	3	6 "	8602	10878	25 43	23 05
3	3	8 "	5801	10417	24 12	22 53
3	3	10 "	4870	7127	21 43	22 49
3	3	12 "	4071	8932	22 07	22 55
3	3	14 "	4071	9007	21 42	22 49

Weight of shot and sabot in both series = 43 lbs.

Constant Weight of Projectile, and Increasing Charges.

For the purpose of determining the difference in pressure at the bottom of the bore due to different weights of powder, with a constant weight of projectile, the following series was fired, with powder which had been well mixed, so as to be as nearly uniform in quality as possible in all the charges, the charges being accurately weighed, and the same shot used throughout the series, sabots being used in all : —

Number of Fires.	Weight of charges.	Pressure per square inch.	Recoil of gun.	REMARKS.
3	3 lbs.	11319 lbs.	10° 38′	
3	4	17483	13 41	Weight of projectile = 43 lbs., including sabot.
3	5	16983	15 00	
3	6	18811	16 51	
3	7	19551	18 42	
3	8	24146	20 01	Radius of arc for measuring recoils = 26 feet.
3	9	28972	21 38	
3	10	32638	22 59	
3	11	37463	24 16	
3	12	38961	25 29	

Constant Weight of Charge, with Increasing Weight of Projectile.

In order to determine the difference in pressure due to a given difference in weights of projectile, with a constant weight of charge, (5 lbs. grained powder,) a sufficient quantity of powder for the series was well mixed together and made into cartridges, all of which were accurately weighed; and from these cartridges the following series was fired, with the results recorded in the following table : —

No. of Fires.	Weight of Charge.	Weight of Projectile.	Pressure per square inch at bottom of bore.	Recoil of gun.
3	5 lbs.	35 lbs.	16733 lbs.	14° 30′
3	5	40	17563	15 08
1	5	45	24226	16 20
2	5	50	27323	17 16
3	5	55	28632	17 55
3	5	60	34966	18 39
3	5	65	32797	19 05
3	5	70	34886	19 49
3	5	75	36964	20 23
3	5	80	38462	21 11
3	5	85	41120	21 47

In order to determine whether the pressure exerted by fired gunpowder,

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partakes more of the nature of a blow, or of a rapidly increased pressure, in its effect upon the gun, three rounds were fired with 10 lbs. powder and 43 lbs. projectile, the indenting tool acting through the breech of the gun, and upon the same specimen, and in the same cavity in that specimen.

The length of the cavity, or indentation, was accurately measured after each fire, but no perceptible enlargement was discoverable after the first fire.

Now a slowly applied pressure, of a given intensity, will produce a certain indentation, and may be repeated almost indefinitely, without perceptibly increasing that indentation, so long as the pressure remains the same at its maximum.

While a single blow, of a given intensity, will also have a corresponding indentation, but every repetition of a blow of equal intensity, will, in performing the same amount of work, which it must do, produce increments of indentation at each repetition corresponding to the living force of the mass producing the blow.

From the foregoing facts and results, we conclude that although the pressure exerted by exploded gunpowder is developed with very great rapidity, yet it does not, in its effect upon the gun, partake of the nature of a blow.

Effects of Windage in the Cartridge.

In order to determine the effect of windage in the cartridge upon the pressure exerted by equal charges, a sufficient quantity of powder for the following series was well mixed together, and made into 8-lb. cartridges, all being accurately weighed.

With these cartridges and the same shot (43 lbs.) the following series was fired, with the results recorded in the following table: —

No. of Fires.	Weight of Charges.	Windage of Cartridge.	Pressure per square inch at bottom of bore.	Recoil of gun.
3	8 lbs.	.2 in.	21060 lbs.	19° 13′
3	8	.4	22228	19 58
3	8	.6	23307	19 55
3	8	.8	23477	19 57
3	8	1.0	22747	20 07
3	8	1.2	22079	19 45
3	8	1.4	21149	19 45
3	8	1.6	19811	19 25
3	8	1.8	19980	19 16
3	8	2.0	19481	19 05
3	8	2.2	18732	18 48
3	8	2.4	18062	18 41
3	8	2.6	17403	18 27

These results, both pressures and recoils, indicate that the pressure increases with the windage, up to about one inch windage, beyond which the pressures and recoils both gradually diminish as the windage in the cartridge increases.

Pressure in the Eprouvette Mortar.

With one ounce of powder and a 24-lb. ball, fired from the old eprouvette at Alleghany Arsenal, the following results were obtained: —

Pressure in the Chamber.

A mean of three rounds gave a pressure in the chamber $= 5481$ lbs. per square inch, with a mean range $= 240$ yards.

Pressure in the Bore.

A mean of two rounds, same charges, gave a pressure at one calibre from mouth of chamber $= 3403$ lbs.

In the foregoing experiments with the 42-pdr. gun, the indentations from which the pressures at the bottom of the bore were determined, were made by a piston having a much longer stem than that which made the indentations from which the pressures at other points were determined. All the foregoing results with that gun show the pressure at the bottom of the bore to be very considerably less than that at two calibres.

In order to reconcile this discrepancy, a piston extending into the surface of the bore, was used at two calibres, and gave at the first fire a pressure of 23504 lbs., and 26560 at the second fire, with 10 lbs. of powder and one solid shot, the piston sticking so tightly in the gun, and housing, that it was with difficulty that it was extracted.

The cause of the piston sticking was that the powder entered the space around the piston, and clogged it so tightly that its indications of pressure were far *below* those obtained with the short piston at the same point, or those obtained at the breech.

The use of both the long pistons was then abandoned; and one, whose inner end did not extend quite through the housing, when in position, with a gas check of thin brass inserted, so as to prevent the gas from clogging the stem, was adopted.

The gas check was a hollow cup made of sheet brass, and of the same or a little greater diameter than the stem of the indenting piston; it was inserted into the mouth of the housing, with its mouth towards the bore of the gun. Its position is shown at (*g*) in the section of the indenting apparatus (Plate 24, fig. 1).

This arrangement was found to entirely prevent the clogging of the stem of the indenting tool, it being generally as free from powder stain when removed, as when inserted.

With the indenting apparatus thus arranged, 10 rounds were fired, five with indenting apparatus at the breech, and five with it at two calibres; charges 10 lbs. each, powder from same barrel, and cartridges all accurately weighed, the same shot being used for the whole 10 rounds.

The results obtained are recorded in the following table: —

NUMBER OF FIRES.	WEIGHT OF CHARGES.		PRESSURE PER SQUARE INCH.	
	Powder.	Projectile.	At bottom of bore.	At two calibres.
1	10 lbs.	43 lbs.	44440 lbs.	41368 lbs.
1	10	43	44440	41556
1	10	43	44440	43718
1	10	43	44440	45129
1	10	43	44918	46069
Mean of five rounds, ...			44535 lbs.	43568 lbs.

These results, especially those at the bottom of the bore, are very uniform, and are doubtless nearer the true pressure due to 10 lbs. of powder and one solid shot, than any results previously obtained.

They also reconcile the discrepancies which occur in the other results, as regards the pressures at the bottom of the bore, and those at two calibres.

Effect of Sabots.

For the purpose of determining the effect of the sabot upon the pressure of gas, velocity of shot, and recoil of gun, 8 rounds of 10 lbs. each of the same quality of powder, and the same shot, 43 lbs., were fired, 4 with and 4 without sabots, with the results recorded in the following table: —

Pressures at Bottom of Bore.

No. of Fires.	PRESSURE PER SQUARE INCH.		VELOCITIES OF SHOT.		RECOIL OF GUN.	
	With sabot.	Without sabot.	With sabot.	Without sabot.	With sabot.	Without sabot.
1	36317 lbs.	36508 lbs.	1494 ft.	1440 ft.	20° 33′	22° 35′
1	37511	38228	1397	1335	21 41	22 11
1	37511	37751	1311	1314	22 56	22 10
1	37990	38228	1141	1336	20 26	21 58
Mean,	37332 lbs.	37679 lbs.	1261 ft.	1356 ft.	21° 28′	22° 13′

It was supposed, from the greater regularity of the results in the table preceding the last, which were obtained without the use of the sabot, than of those previously obtained with sabots, that the use of the sabot introduced by its irregular action, irregularity of pressure, velocity of shot, and recoil of gun.

The foregoing results, however, show no very marked difference in this respect, the pressures being more regular *with* than *without* sabots.

The velocities and recoils are, however, less regular with the sabot than without it, and it is believed that the sabot should be used only when absolutely necessary.

The powder with which the results recorded in the above table were obtained, had remained at the proving ground two days previous to its use; this is the only assignable reason why the pressures in this series should be less than those in the series preceding it.

Greater Uniformity of Pressure from Accelerating Charges.

Pressure due to 10 lbs. grained powder and 1 solid shot without sabot at 4 calibres from bottom of the bore, with improved indenting apparatus, and a mean of 3 rounds, = 12300 pounds, or about 3000 lbs. less than that due to $12\frac{1}{4}$ lbs. accelerating cartridge at the same distance from bottom of bore; while the pressure at the bottom of the bore with the grained powder is one-half, or about 15000 lbs. greater; thus showing much greater uniformity of pressure from the accelerating than from the grained cartridge.

Accelerating Cartridges.

With a view to determine the velocity of shot and pressure of gas with

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improved indenting apparatus, six rounds were fired with accelerating cartridges of $12\frac{1}{4}$ lbs. each and 1 solid shot without sabot; three rounds being fired for pressure at the bottom of the bore, and three for that at 4 calibres.

The results are recorded in the following table: —

No. of Fires.	Pressure at the bottom of bore.	Velocity of shot.	Recoil.
1	17203 lbs. per inch.	1088 feet.	20° 22′
2	27715	1513	Failed.
3	45874	1466	24° 00′
Mean, . . .	30264 lbs. per inch.	1356 feet.	Slide broke.
	Pressure at 4 calibres.	Velocity of shot.	
4	16923 lbs. per inch.	1449 feet.	
5	12224	1463	
6	15983	1318	
Mean, . . .	15043 lbs. per inch.	1382 feet.	

The above results show the pressure of gas at 4 calibres to be about half that at the bottom of bore.

Time of Combustion of Charge.

With a view to determine the time during which the shot remains in the gun after the ignition of the charge, the following trials were made with M. Navez' pendulum, and with the following results: —

With the 10-inch Gun.

With one wire across the tube in the vent, and the other across the muzzle of the gun, the time which elapsed between the cutting of the wires was for a mean of 2 rounds, with 15 lbs. powder and one solid shot and sabot, $t = .0132''$; the first fire giving $t = .016843''$, and the second $t = .009557''$.

With the 42-pdr. Gun.

With the same arrangement of wires as above, with 10 lbs. powder and 1 shot, the following results were obtained, viz.: —

1st fire,	.	.	.	.	.	.	$t = .012068''$
2d "	.	.	.	.	.	.	$t = .012597''$
3d "	.	.	.	.	.	.	$t = .020774''$
Mean,	.	.	.	.	.	.	$t = .017479''$

One wire at the *breech* and the other at the muzzle, and same charges as above, gave, —

1st fire,	.	.	.	.	.	.	$t' = .005553''$
2d "	.	.	.	.	.	.	$t' = .004049''$
3d "	.	.	.	.	.	.	$t' = .006973''$
4th "	.	.	.	.	.	.	$t' = .004447''$
5th "	.	.	.	.	.	.	$t' = .005659''$
Mean,	.	.	.	.	.	.	$t' = .005334''$

One wire at 2 *calibres*, and the other at the muzzle, same charge as above, gave for the —

1st fire,	.	.	.	.	.	.	$t'' = .002449''$
2d "	.	.	.	.	.	.	$t'' = .001226''$
3d "	.	.	.	.	.	.	$t'' = .001960''$
Mean,	.	.	.	.	.	.	$t'' = .001878''$

Had the results obtained been more regular, it was intended to determine the time occupied by the shot in passing over different sections of the bore from the seat of the shot to the muzzle, by placing the rear wire of the pendulum at 4, 6, 8, 10, 12 and 14 calibres; but the indications of the instrument were not considered to justify a further prosecution of the subject.

Thus we have $t - t' = .012145''$, for the time which elapsed between the ignition of the charge and the starting of the shot; and $t' - t'' = .003456''$, for the time required for the shot to reach the position of 2 calibres from the bottom of the bore, a distance of not over 2 inches from its seat in the gun; while (t'') the time required for the shot to pass from 2 calibres to the muzzle is only $= .001878''$.

With the improvements of which this instrument is believed to be susceptible, it is believed that the velocity of the shot, and consequently the pressure of the gas for any required length of surface pressed, may be closely approximated to by this method.

And owing to the different velocities with which the gas passes the orifices which communicate with the indenting piston, and to the difference in length

of the times during which the gas acts upon that piston, at different points along the bore, it would free the results, for distances beyond two calibres, by the method of pistons, from the doubt which attaches to them, if they could be corroborated by some other method.

For the maximum pressure, that at the bottom of the bore, and at 2 or even 3 calibres from the bottom, it is not perceived how the method of indentations, with gas check and freely moving piston, can give results differing by any important quantity from the true pressure.

All the foregoing results are regarded rather as preliminary than as conclusive on the points to which they refer; for it is believed that many of the discrepancies which occur in these results would disappear under a greater number of trials, and more experience in perfecting the means of investigation.

Bursting Tendencies.

The nearest approximation to any regular law of variation of pressure due to variation of charge and projectile, discoverable in the results obtained from the series, with a constant weight of projectile and variable weight of charge, and that with a constant weight of charge and variable weight of projectile, is, that with a constant diameter of bore the pressure increases directly as the product of the weights of the charge by that of the projectile.

Or, if we may suppose the shot and charge each reduced to a right cylinder whose base equals a cross section of the bore, then the pressure would be directly as the product of the height of the cylinder of powder by that of the cylinder of metal.

And although I am not aware that it has been so established by experiment, yet it would seem to be almost axiomatic that the same column of powder, behind the same column of metal, would give the same pressure, irrespective of the diameter of the bore, provided the diameter of the cylinders of powder and metal are each equal to that of the bore of the gun in which it is fired.

Now a 42-pdr. shot would give a cylinder of the diameter of the bore of that gun equal to 4.66 in. in height; and 10 lbs. of powder, at 30 cubic inches to the lb., would give a cylinder of the same diameter = 8 inches in height. The product of the heights of these cylinders = $4.66 \times 8 = 37.28$.

The most reliable results in the foregoing experiments give the pressure due to 10 lbs. powder and one solid shot, at about 45000 lbs. per square inch. This, divided by 37.28, gives say 1200 lbs. for the *general* coefficient of pressure.

This coefficient, therefore, multiplied by the product of the height of the column of powder by that of the column of metal, will give the pressure due to any given weight of powder and projectile fired in any diameter of bore.

The hypothesis on which the coefficient of pressure depends, is believed to be more strictly true for those heights of the cylinder of powder which lie between half a calibre and one and a half calibres of the bore in which the charge is fired.

Knowing the actual pressure per square inch due to any weight of powder and projectile, and the resistance which the gun is capable of offering to that pressure, we can determine the bursting tendency due to any given weight of powder and shot in any gun at each discharge.

The bursting tendency is the ratio of the bursting effort divided by the total resistance which the gun is capable of offering.

The bursting effort against one side of a gun is the pressure per square inch, into the product of the radius of the bore, by the length of bore to which the pressure is applied.

Let (R) = exterior radius of gun, r = radius of bore, L = length of bore to which the pressure is applied, l = length of surface pressed which fully develops both transverse and tangential resistance, p = pressure per square inch, and S = tensile strength of metal.

Then $(p\,r\,L)$ = rupturing effort, and $\dfrac{L\,S\,(R\,r^2 - r^3)}{R\,r}$ = tangential resistance, and $\dfrac{3\,S\,(R+r)\,(R-r)^2\,l^4}{2\,L^5}$ = transverse resistance; and we have for

bursting tendency $z = \dfrac{p\,r\,L}{\dfrac{L\,S\,(R\,r^2 - r^3)}{R\,r} + \dfrac{(3\,S\,(R+r)\,(R-r)^2\,l^4}{2\,L^5}}$

$$= \frac{2\,p\,R\,r^2\,L^6}{r^2\,S\,(R-r)\,2\,L^6 + 3\,R\,r\,S\,(R+r)\,(R-r)^2\,l^4}$$

$$= \frac{2\,p\,R\,r\,L^6}{S\,(R-r)\left(2\,L^6\,r + 3\,R\,(R+r)\,(R-r)\,l^4\right)}; \quad \text{or if } h$$

= height of cylinder of powder, and h' that of cylinder of shot, we have, by taking coefficient of pressure = 1250 lbs., and substituting for (p) its value

1250 $h\,h'$, in the above equation, $z = \dfrac{2500\,h\,h'\,R\,r\,L^6}{S\,(R-r)\left(2\,r\,L^6 + 3\,R\,(R+r)\,(R-r)\,l^4\right)}$

as the general expression for the bursting tendency.

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The length of bore in which the maximum pressure is exerted does not generally exceed the value of (l); and since the transverse resistance will be fully developed for all values of (L) less than (l), the foregoing equation will, for all such values of (L), become $z = \dfrac{2500\, h\, h'\, R\, r\, L}{S\,(R-r)\left(2\,r\,L + 3\,R\,\dfrac{(R+r)\,(R-r)}{L}\right)}$.

The bursting tendencies of our siege and garrison guns, assuming S = 20000 lbs., as determined by this formula, are as follows, viz. :—

For the 24-*pdr. gun*, with 8 lbs. powder and one solid shot, supposing
$L = 13$ inches, we have for bursting tendency at each discharge, $z = .837$
For 32-*pdr. gun*, with 8 lbs. powder and one solid shot, supposing
$L = 12$ inches,   -   -   -   -   -   - $z = .656$
For 42-*pdr. gun*, with 10 lbs. powder and one solid shot, supposing
$L = 13$ inches,   -   -   -   -   -   - $z = .744$
For 8-*inch gun*, with 10 lbs. powder and one solid shot, supposing
$L = 12$ inches,   -   -   -   -   -   - $z = .528$
For 10-*inch gun*, with 14 lbs. powder and one solid shot, supposing
$L = 14$ inches,   -   -   -   -   -   - $z = .498$

It thus appears that our 24-pdr. is the most heavily strained gun, and that the 10-inch is the least strained gun at each discharge, of the two classes above referred to; and if their endurance be not found in accordance with the above estimates, it is believed that the only reason why it will not, is, that the larger guns are more injured by contraction in cooling than the smaller.

The bursting tendency of the 11-inch Navy gun, with 15 lbs. powder and 135 lbs. shell, supposing $L = 15$ inches, is $z = .477$.

The same formula gives the bursting tendency of a 15-inch gun of 46 inches exterior diameter, with 35 lbs. powder and 343 lbs. loaded shell, supposing $L = 18$ inches, $z = .577$, which is less than for the 32-pdr. gun.

Repetition of Strain.

A specimen from the Fort Pitt solid cast gun of 1857 broke at the 1956th repetition of a strain equal to three-fourths of its ultimate strength.

The 42-pdr. gun is shown (above) to be subjected, at each discharge, to

.744 thousandths, or about three-quarters of its ultimate strength, and there is no reason, other than the difference in mode of application of the force, why that gun should not endure 2000 rounds, if uninjured in cooling.

The 10-inch gun, as shown above, is subjected, at each discharge, to a strain of less than half its ultimate strength; and two guns of this calibre have endured, without breaking, 2452 rounds each.

These results leave no doubt, in my mind, that a 15-inch gun may be safely estimated to endure 1000 rounds of charges proportional to those above named.

T. J. RODMAN,
Capt. of Ordnance.

REPORT

OF

EXPERIMENTS

MADE BY

CAPT. T. J. RODMAN, U. S. ORDNANCE DEPARTMENT,

AT THE

WATERTOWN ARSENAL, IN THE 2D HALF OF 1859,

FOR DETERMINING THE PROPER QUALITIES OF IRON,

EXTERIOR MODEL, ETC., FOR CANNON,

WITH SPECIAL REFERENCE TO THE

FABRICATION OF A 15-INCH GUN.

REPORT

EXPERIMENTS MADE BY CAPTAIN T. J. RODMAN, AT THE WATERTOWN ARSENAL, IN THE SECOND HALF OF 1859, FOR THE PURPOSE OF DETERMINING THE PROPER QUALITIES OF IRON, EXTERIOR MODEL, ETC., FOR CANNON, WITH SPECIAL REFERENCE TO THE FABRICATION OF A 15-INCH GUN.

For the purpose of determining the relation between the thickness of metal and the tangential resistance offered by hollow, open ended cylinders, the following experiments were made : —

Three similar solid iron castings, of circular cross section, were cast, on end, in dry sand moulds, out of the same ladle of melted metal.

These castings were of sufficient length to furnish six cylinders each, and one specimen each, five inches long, for tenacity.

These castings were of different diameters, thus: —
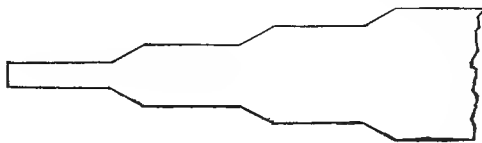
So that each cylinder should have the same amount to be turned off in reducing it to its proper exterior dimensions. They were all accurately

bored to two inches, interior diameter, were 12 inches long, and varied in thickness from .5 in. to 3 in. by difference of .5 in.

Each set in the tables was composed of one cylinder from each casting, and from corresponding parts. The castings were cast with their small ends down, and the specimens for tenacity were taken from the lower ends.

The cylinders were burst with powder of .3 to .4 in. in diameter of grain, and their bursting pressures determined by the method of indentations heretofore explained; they were placed in a strong, heavy housing of cast iron, and their ends firmly closed when fired.

The annexed drawing (Plate No. 1) shows the arrangement referred to; (a) large housing in which the cylinder is confined, (b) plugs for closing ends of cylinders, (c) shoe to receive end of plug, (d) key for forcing shoulders of plugs against end of cylinders, (C) cylinders, (g) gas checks to ends of cylinders, (v) vent through which the powder was fired, and (i) indenting apparatus.

The plugs entered the ends of the cylinders .1 inch, with a snug fit; they were at first made of cast iron, and both broke; that which rested in the shoe had the shoulders first cut in by the gas, as shown at (e,) and afterwards blown off entirely; while that which received the indenting apparatus was split entirely through, and broken transversely. The plugs were then replaced with others made of cast steel, and the end of that into which the indenting housing was secured, twice pulled off at the bottom of the cavity which received the indenting housing, or on the section ($h\,i$).

The castings from which the cylinders were prepared were designated A, B, and C, and the results obtained are recorded in the following tables: —

Number of sets.	Thickness of metal.	Bursting pressure in lbs. per square inch.			Mean bursting pressure per square inch.	Difference.
		A	**B**	**C**		
1	.5 inch.	37609	38077	37842	37842	–
2 { 1st fire, 2d "	1.	37609 37137	39253	38077	38313	471
3	1.5	62759	66753	60640	63384	25071
4	2.	79916	80385	80385	80229	16845
5	2.5	94618	74803	*89922	92270	12041
6	3.	*77985	89525	97879	93702	1432
Tenacity, · · · · · · · · · ·		27950	24500	28150	26866	

* Not burst. A (6) and B (5) neglected.

PLATE I

Section on CD.

Section on AB

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The following table compares the above mean result with those computed on the hypothesis that the strain diminishes as the square of the distance from the axis increases, and multiplying the tenacities by such coëfficient as makes the actual and computed resistance equal for one inch thickness of metal :—

Number of sets.	Mean bursting pressure by experiment.	Difference.	Computed bursting pressure.	Difference.
1	37842	–	25541	–
2	38313	471	38313	12772
3	63384	25071	46057	7744
4	80229	16845	51085	5028
5	92270	12041	54732	3647
6	93702	1432	57468	2736

The most remarkable features in these results are the very small difference in bursting pressure between the first and second sets, and that the bursting pressures, not only in these two sets, but in the whole series, are greater than required by the tenacity of the iron, even supposing the whole thickness of metal to resist uniformly as in tensile strain.

The uniformity in the bursting pressures of the three specimens in each set Nos. 1 and 2, would seem to forbid the conclusion that these results are accidental.

These two sets were charged, and burst, with equal charges of powder; and the fact that specimen (A 2) required two charges to burst it, indicates that the resistance of the 2d set was nearly equal to the bursting effort of the charge of powder used; viz., .75 lbs., while the bursting effort of the charge of powder must have been greatly in excess of the resistance offered by set No. 1, and the time during which the bursting force acted on set No. 1 must have been much less than that during which it acted on set No. 2.

There is a certain amount of work to be done in rupturing a specimen of any solid substance, and the less the time occupied in accomplishing that work, the greater must be the force. The time during which the explosive force of the powder was occupied in bursting any one of the series of cylinders was exceedingly short, in comparison with that required for rupturing a specimen on the testing machine, and consequently the force was greater.

These considerations offer the most probable explanation of these results

which now presents itself to my mind, and further experiments alone can tell us whether or not they are sufficient.

The column of differences in the foregoing table shows a constant, though irregular, diminution in the resistance added by equal increments of thickness, from the second to the fifth set, and from the fact that (C 5) endured, without bursting, a greater pressure than burst (B 6), we conclude that the last increment added very little to the reliable strength of the cylinder.

And the fact that (B 5) burst with so much less pressure than (A 5 and C 5) and even less than (B 4), would seem to indicate that (B 5) ought to be neglected as accidental.

Neglecting (B 5) gives a continuous, though still irregular, diminution of resistance offered by the successive equal increments of thickness after the first.

And although these results are not sufficiently regular to warrant the deduction from them of the true law of diminution in value of equal increments of thickness, yet they leave no doubt of the fact that there is a very important diminution in that value as the thickness increases.

For the purpose of determining the difference in pressure due to equal columns of powder behind equal columns of metal, when fired in guns of different diameters of bore, the following experiment was made : —

Three guns, one 42-pdr., (or 7-inch bore,) one 9-inch and one 11-inch bore, were prepared for experiment by reaming out the chambers of the 9-inch and 11-inch guns, (Navy guns — Dahlgreen's Model,) so as to conform in shape with the termination of bore of the Army 42-pdr., the radius of curvature of the surface joining the bottom and sides of the bore, bearing the same proportion to the diameter of bore in all of the three guns.

These guns were all pierced with holes .4 in. diameter; one at the bottom of the bore and six others at intervals of 14 inches from the bottom, towards the muzzle. To each of these holes was adapted a small housing for determining the pressure of the gas by the method of indentations.

The charges of powder and the weight of projectiles were computed so that there should be the same weight of powder behind, and the same weight of metal in front of each square inch of area of cross section of the bore or surface of projectile passed by the gas in all the guns.

The projectiles used were cylindrical, and accurately turned to such diameters that the area of the windage space should bear the same proportion to that of a cross section of the bore in all the guns.

The data for pressure of gas at the bottom and six points along the bore of the gun were taken at each discharge, and the housings which held the specimens of copper to be indented were taken out, and the indenting pistons carefully cleaned after each discharge, so that all the circumstances of each discharge should be as nearly identical, one discharge with another, as possible.

The charges were accurately weighed, a sufficient quantity of powder for ten rounds with each gun having been well mixed together, so as to insure identity in quality of the powder used in all these guns.

The powder used was Hazard's, of 1858, proof range 280 yards. Cartridge blocks were used in all, and the cartridges fit snugly in the bore, so that there was no vacant space either around the cartridge or between the cartridge and the projectile.

The velocity of the shot was determined by the use of M. Navez' electro-ballistic pendulum at each fire. The following tables exhibit the results obtained : —

TABLE *showing the velocity of shot, in feet, per second, and pressure of gas per square inch, in pounds, due to 5.13 lbs. of powder, and one cylindrical shot of 75.44 lbs. with .07 in. windage, fired in a 42-pdr. gun.*

Number of Fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 inches.	At 28 inches.	At 42 inches.	At 56 inches.	At 70 inches.	At 84 inches.
1	922	38000	14000	8750	8000	8000	8750	13000
2	899	37750	16251	8250	6500	6250	7000	5750
3	853	41000	19000	8500	6500	7250	8750	6750
4	815	32500	16250	8250	6000	7750	5750	6000
5	941	34000	14000	8250	6000	6500	9000	5750
6	882	32750	16250	8500	6000	6000	8750	5750
7	856	32750	14750	8250	6500	6000	7000	5750
8	944	37500	16500	9000	6500	7500	8500	6500
9	1031	40000	14000	8000	6000	6000	8500	6000
10	894	38000	17500	8000	6750	7250	8500	6000
Mean,	904	36420	15850	8370	6470	6850	8050	6720

TABLE *showing the velocity of shot, in feet, per second, and pressure of gas per square inch, in pounds, due to 8.48 lbs. of powder, and one cylindrical shot of 124.42 lbs. with .09 in. windage, fired in a 9-inch gun.*

Number of Fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 inches.	At 28 inches.	At 42 inches.	At 56 inches.	At 70 inches.	At 84 inches.
1	952	38000	24000	22500	17000	24000	26000	20000
2	911	76000	20000	15500	15000	35000	19000	27000
3	867	67000	23000	27500	14000	26000	26000	21000
4	895	61000	29500	16000	14000	31000	16000	24000
5	Failed	73000	18000	14500	14000	30500	16250	20250
6	858	61000	20000	15500	15000	32000	21250	27000
7	870	67000	14500	18400	15000	31250	29000	28500
8	932	73000	24500	18000	17000	28000	21250	19500
9	861	88000	19500	14500	14000	26000	19000	19500
10	845	67000	18000	15500	14000	31000	16000	21500
Mean,	888	67100	21100	17750	14900	29457	20970	22825

TABLE *showing the velocity of shot, in feet per second, and pressure of gas per square inch, in pounds, due to 12.67 lbs. of powder and one cylindrical shot of 186.3 lbs., with .11 in. windage, fired in an 11-inch gun.*

Number of fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 in.	At 28 in.	At 42 in.	At 56 in.	At 70 in.	At 84 in.
1	Failed.	75000	23000	20000	18000	19000	29500	16000
2	917	86000	32500	25500	21500	27000	38000	20000
3	920	94000	31000	30000	21000	27000	31500	22500
4	934	56500	28000	25000	22000	29000	34000	25500
5	Failed.	95000	29500	31500	29000	27000	29500	22500
6	920	100000	36000	35500	19000	31500	38000	31000
7	1051	95000	26000	25000	18000	31500	28000	29000
8	971	94000	28000	30000	26500	29000	38000	29000
9	767	80000	31000	25500	18250	31500	38000	26000
10	935	94000	28000	30000	21000	31500	34000	29000
Mean, .	927	86750	29300	27800	22420	28400	33850	25050

TABLE *showing the velocity of shot, in feet per second, and pressure of gas per square inch, in pounds, due to equal columns of powder behind equal columns of metal, when fired in guns of different diameter of bore, each result being a mean of ten fires.*

Diameter of Bore.	Windage.	Weight of Charge.	Weight of Shot.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
					At bottom.	At 14 in.	At 28 in.	At 42 in.	At 56 in.	At 70 in.	At 84 in.
7 in.	.07	5.13 lbs.	74.44 lbs.	904	36420	15850	8370	6470	6850	8050	6720
9	.09	8.48	124.42	888	67100	21100	17750	14900	29475	20970	22825
11	.11	12.67	186.03	927	86750	29300	27800	22420	28400	33850	25050

The points most worthy of note in these results, are the very marked increase in pressure of gas as the diameter of bore increases; and that the indications of pressure are greater at 56 inches, 70 inches, and 84 inches, than at 42 inches, especially in the 9-inch and 11-inch guns.

The cause of the difference in pressure developed in these guns of different diameters of bores, is believed to be mainly due to the greater heat developed by the combustion of the larger mass of powder in the large than in the smaller calibre; and perhaps, also, to the different products of combustion formed under this increased temperature and pressure, and partly to the greater cooling surface in proportion to the weight of charge in the small than in the larger calibre.

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From the fact that there was no vacant space around the cartridge, all the powder that was burned before the shot moved must have been burned in its own volume, and the maximum pressure would probably be reached before the charge would be nearly consumed, and a greater proportional quantity of gas would escape through the vent of the smaller calibre. The vent in the 42-pdr. was something larger than those in the 9-inch and 11-inch guns, it having been fired some 200 rounds before this series was commenced. The vents in the 9-inch and 11-inch guns were new, and .2 inches in diameter.

It is impossible that there could have been any greater pressure beyond 42 inches than at that point; and it cannot be doubted that the pressure diminishes, as the space occupied by the products of combustion of a given weight of powder increases.

The greater indications of pressure *beyond* than *at* 42 inches, is believed to be due to the more violent and sudden contraction of the metal in the thin than in the thick part of the gun, and to the greater number of vibrations to which the thin portions are subjected at each discharge.

The point 42 inches from the bottom of the bore falls on the rapid taper from the cylinder to the chase, which occurs in these guns, and it is believed that the true pressures are indicated with sufficient accuracy up to this point.

For in the thick part of the gun the pressure is much less rapidly developed, and subsides much more gradually, the contained gas forming an elastic cushion, which would, if the bore were long enough, allow this part of the gun to return from its strained to its free condition, without any vibration at all.

While in the model used in these experiments the pressure is almost instantaneously developed, and as suddenly subsides in the chase of the gun, so that while the indenting piston is on its way outward, it is suddenly met by the returning specimen, which is drawn in along with the housing by the contraction of the gun, with such violence as to amount, in effect, to a smart blow of the indenting tool against the specimen. Close examination shows a number of marks or cuts of the indenting tool on the specimen in this part of the gun, caused by the tool not striking in the same place at each vibration of the gun.

Further evidence of this action is found in the fact that the specimens frequently jarred out of the housing in this part of the gun, but never in the thick part. The same thing occurs, though in a much less degree, in the

42-pdr. The chase of this gun is much thicker in proportion than in the 9-inch and 11-inch guns, and the taper much more gradual.

It is believed that true indications of pressure along the whole length of bore can only be obtained, by this method, from a gun of great and uniform thickness along its entire length; so that there should be the least possible enlargement of its exterior diameter, and consequently the least vibration at each discharge.

For the purpose of determining the difference in pressure of gas, and velocity of shot, due to equal weights of powder of the same quality in all respects, except in diameter of grain, fired from the same gun, the following experiments were made :—

Powder of the same quality in every respect, except in diameter of grain, was prepared by the Messrs. Dupont.

The powder varied in size of grain as follows : —.1 in., (ordinary cannon powder,) .15 in., .2 in., .25 in., .3 in. and .4 in. diameter of grain. Five rounds of 8 lbs. each were fired, with each size of grain, from the 42-pdr. gun, with one solid shot and sabot, the same shot being used in all the firing.

The pressure of gas at the bottom of the bore, and at six other points along the bore, at intervals of 14 inches from the bottom, was determined at each discharge by the method of indentations, and the velocity of the shot at each fire was determined by the use of M. Navez' electro-ballistic pendulum.

The eprouvette range of the different sized grains of powder was carefully determined, each result being a mean of three rounds.

The results are given in the following tables : —

TABLE *showing the velocity of shot, in feet per second, and pressure of gas per square inch, in pounds, due to 8 lbs. of powder, (grain .1 in. diameter,) and one solid shot and sabot, fired in a 42-pdr. gun.*

Number of Fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 in.	At 28 in.	At 42 in.	At 56 in.	At 70 in.	At 84 in.
1	Failed.	49000	51000	13500	13000	10000	10500	7500
2	Failed.	49000	47000	13000	7000	6000	6750	6500
3	1242	45000	49500	10000	8500	5500	5750	5750
4	1235	49000	51000	14000	7000	6000	6750	6500
5	1307	49000	60000	17000	7000	10250	6750	7250
Mean, .	1261	48200	51800	13500	8900	7550	7300	6700

TABLE *showing the velocity of shot, in feet per second, and pressure of gas per square inch, in pounds, due to 8 lbs. of powder, (grain .15 in. diameter,) and one solid shot and sabot, fired in a 42-pdr. gun.*

Number of Fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 in.	At 28 in.	At 42 in.	At 56 in.	At 70 in.	At 84 in.
1	Failed.	58000	50000	17000	11500	10250	11000	10000
2	1259	45000	50000	13000	7000	7000	6750	6500
3	Failed.	45000	49500	17000	7000	6750	5750	6250
4	1230	45000	47500	13500	7000	7000	5750	6500
5	1215	43000	44500	17000	7000	5750	5750	5750
Mean, .	1235	47200	48300	15500	7900	7350	7000	7000

TABLE *showing the velocity of shot, in feet per second, and pressure of gas per square inch, in pounds, due to 8 lbs. of powder, (grain .2 in. diameter,) and one solid shot and sabot, fired in a 42-pdr. gun.*

Number of Fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 in.	At 28 in.	At 42 in.	At 56 in.	At 70 in.	At 84 in.
1	1257	49000	42500	10000	4750	5000	4750	5500
2	Failed.	43500	50000	12750	5750	5750	4850	5500
3	1156	36000	40500	12750	6000	6000	5250	6500
4	1184	38000	47500	12750	4750	5000	4850	5500
5	Failed.	45000	50000	12750	6250	5000	5250	5500
Mean, .	1199	42300	46100	12200	5500	5350	4970	5700

TABLE *showing the velocity of shot, in feet per second, and pressure of gas per square inch, in pounds, due to 8 lbs. of powder, (grain .25 in. diameter,) and one solid shot and sabot, fired in a 42-pdr. gun.*

Number of Fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 in.	At 28 in.	At 42 in.	At 56 in.	At 70 in.	At 84 in.
1	1141	41500	40500	15000	4750	5000	4250	5000
2	1141	36000	44500	14000	5750	4000	4250	5750
3	Failed.	36000	47500	10000	5750	5750	4750	5000
4	1119	43000	40000	15000	4750	5750	4750	5500
5	1202	36000	49500	10000	4000	5750	5250	6250
Mean, .	1151	38500	44400	12800	5000	5250	4850	5500

TABLE *showing the velocity of shot, in feet per second, and pressure of gas per square inch, in pounds, due to 8 lbs. of powder, (grain .3 in. diameter,) and one solid shot and sabot, fired in a 42-pdr. gun.*

Number of Fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 in.	At 28 in.	At 42 in.	At 56 in.	At 70 in.	At 84 in.
1	1185	29000	32250	9500	6000	4500	4250	5000
2	Failed.	33500	32750	15000	6250	5000	4250	5500
3	1152	38000	32000	14000	3750	4000	4750	4500
4	1088	38000	32000	10000	4300	4250	4150	5000
5	1157	33500	30000	17000	3750	4000	4500	4500
Mean, .	1146	34400	31800	13100	4810	4350	4380	4900

TABLE *showing the velocity of shot, in feet per second, and pressure of gas per square inch, in pounds, due to 8 lbs. of powder, (grain .4 in. diameter,) and one solid shot and sabot, fired in a 42-pdr. gun.*

Number of Fires.	Velocity.	PRESSURE AT DIFFERENT DISTANCES FROM BOTTOM OF BORE.						
		At bottom.	At 14 in.	At 28 in.	At 42 in.	At 56 in.	At 70 in.	At 84 in.
1	Failed.	28500	32000	10500	4000	4500	4750	5500
2	1157	38000	33000	13000	4000	4500	4250	5500
3	Failed.	36000	32000	17000	4000	4000	5250	6250
4	1197	28500	30000	13000	4300	3750	4200	4250
5	1208	28500	32750	13500	4000	4000	4300	4250
Mean, .	1187	31900	31950	13400	4060	4150	4550	5150

Proof Range, by Eprouvette, of Powder used in the Experiments whose results are recorded in the foregoing tables, as determined August 15, 1859, *at Watertown Arsenal.*

DUPONT'S, OF 1859, OF DIFFERENT SIZED GRAINS.

DIAMETERS OF GRAINS.	PROOF RANGES.			
	1st Fire.	2d Fire.	3d Fire.	Mean.
.1 inch.	314 yards.	295 yards.	305 yards.	305 yards.
.15	284	285	282	284
.2	263	252	257	257
.25	154	154	170	159
.3	90	73	88	84
.4	52	51	54	52

Hazard's, of 1858, used in determining difference of pressure of equal columns of powder behind equal columns of metal, in guns of different diameter of bore :—

1st fire,	. . . .	296 yards.
2d "	. . . .	284 "
3d "	. . . .	261 "
Mean,	. . . .	280 yards.

TABLE showing the velocity of shot, in feet per second, and the pressure of gas. per square inch, in pounds, due to equal charges of powder, of the same composition, and differing only in size of grain, each result being a mean of five fires with the 42-pdr. gun ; the same shot being used in all the fires.

Diameters of Grains.	Weight of Charge.	Weight of Shot and Sabot.	Velocity of Shot.	Proof range of Powder.	PRESSURE OF GAS AND DISTANCE FROM BOTTOM OF BORE.						
					At bottom.	At 14 inches.	At 28 inches.	At 42 inches.	At 56 inches.	At 70 inches.	At 84 inches.
.1 inch.	8 lbs.	43 lbs.	1261	305 yds.	*48200	51800	13500	8900	7550	7300	6700
.15	8	43	1235	284	*47200	48300	15500	7900	7350	7000	7000
.2	8	43	1199	257	*42300	46100	12200	5500	5350	4990	5700
.25	8	43	1151	159	*38500	44400	12800	5000	5250	4850	5500
.3	8	43	1146	84	34400	31800	13100	4810	4350	4380	4900
.4	8	43	1187	52	31900	31950	13400	4060	4150	4550	5150

* Small quantities of gas were found to escape at the bottom of the bore at these fires, which was prevented in the subsequent fires. This escape of gas is believed to be the cause of the indication of pressure being less at the bottom of the bore than at 14 inches.

The point of greatest interest in these results, is the fact that the maximum pressure of gas diminishes as the diameter of grain increases, in a much greater ratio than the squares of the corresponding velocities; thus showing, conclusively, that the velocities due to our present charges of small grained powder may be obtained with a greatly diminished strain upon the gun, by the use of powder properly adapted in size of grain to the calibre and length of bore in which it is to be used; or that increased velocities may be thus obtained, without any increase of the strain to which our guns are now subjected, in obtaining our present velocities.

The results also show the impropriety of taking the eprouvette range as an indication of the projectile force of powder which is to be used in guns of any considerable length and calibre.

Powder intended to be used in mortars should be proved in mortars, and that for guns should be proved in guns.

It will be observed that the minimum indications of pressure in these experiments are at 70 inches instead of 42 inches, as in the previously described series; this is believed to be due to the greater charges used in this than in the other series.

For the purpose of determining the pressure exerted by exploded gun-powder, when the products of combustion occupy a certain number of times the volume occupied by the powder before combustion, the following experiments were made:—

A shell was cast of the best gun iron, with a spherical cavity of 5 inches diameter, and 6.25 in. thickness of walls.

This shell was pierced with a hole .4 in. diameter, and concentric with that into which the housing or indenting apparatus was screwed, and the hole left by the core stem, 90° from it, was reamed out to the depth of 2.5 in., and tapped so as to receive a plug 1.5 in. diameter.

This plug had a hole .4 in. bored out along its axis, and was tapped at its inner end so as to receive another small plug, which was pierced along its axis with a hole .1 in. diameter, which was the only outlet for the products of combustion when the charge was fired.

This plug was replaced by a new one, when the hole in it was burned out to .125 in. The interior volume of the shell, with plug and housing screwed

PLATE II.

6.25

5

P

17 5.
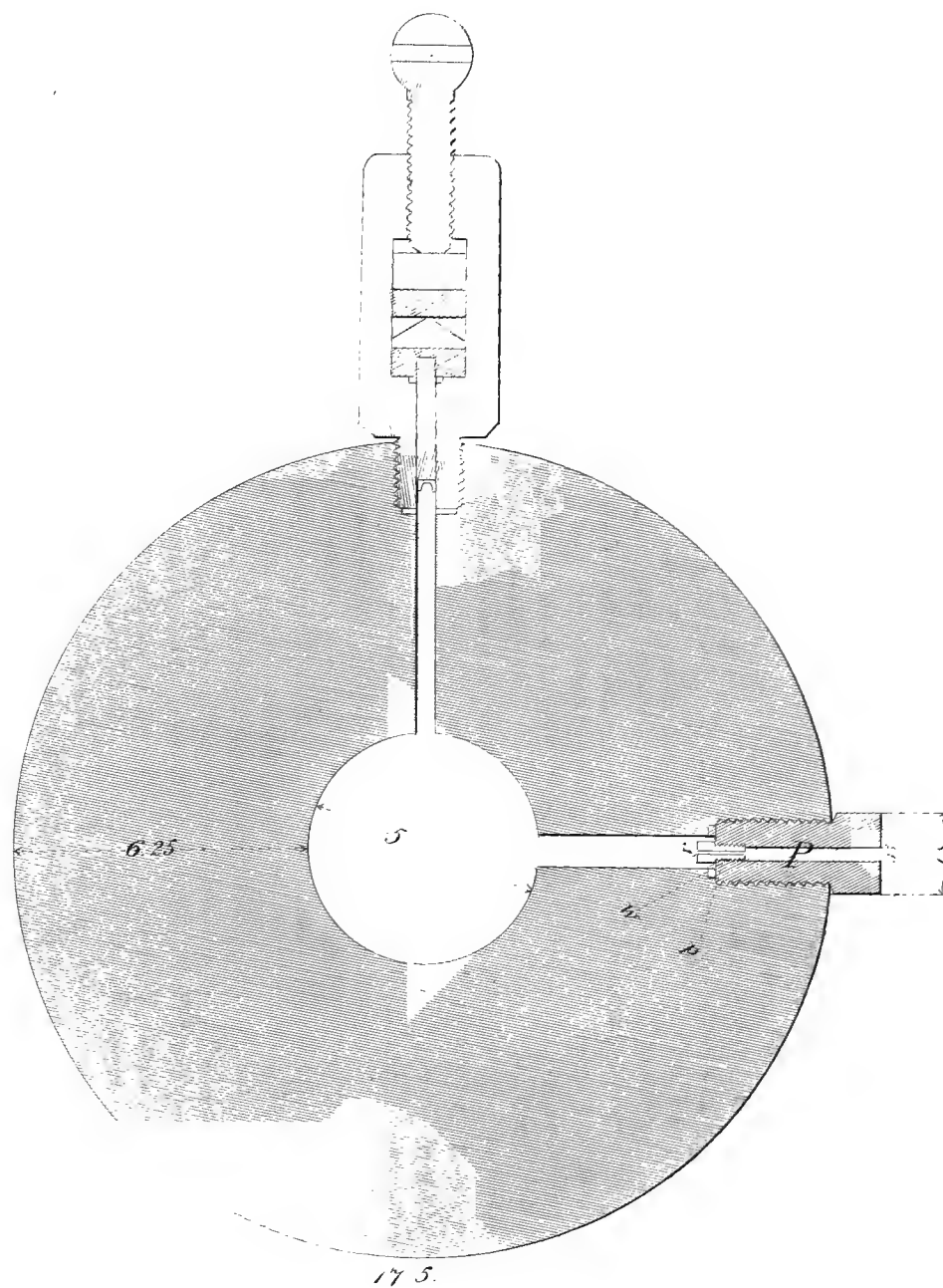
Scale ¼

into their places, was such as to hold exactly two pounds of powder, determined by trial, the powder being well shaken by striking the shell with a heavy mallet.

The charges were all accurately weighed, and were fired by friction tubes inserted in the plug (P) (Plate No. 2). The pressure was determined by the method of indentation, the indenting apparatus being shown in position at (I) (Plate No. 2).

It was found necessary to remove the wax from the ends of the friction tubes used in this experiment, as the force of the charge in the tube was not sufficient to drive the wax through the small hole in the inner plug (p) (Plate No. 2).

The shell was carefully washed out after every ten fires while the charges were small, and oftener as they increased.

The interval between fires was about three minutes; and the second charge of 1000 grains exploded just as the last grains of powder had been poured in, blowing out a copper washer, used for making a gas-tight joint at (w,) (Plate 2) which struck me on the side of the face.

This accident is believed to have resulted from small pieces of wire, used for confining the core and lapping the core stem in casting, remaining in the cavity of the shell. Several pieces of wire were found in the top of the bulkhead, in which the shell was fired, which had been blown out of the shell. This wire would be heated, probably, to redness, or even higher, by the combustion of 1000 grains of powder, and would retain sufficient heat to ignite the succeeding charge three minutes after. There is no other assignable cause, as the shell was dry, and nothing but the clean powder put into it.

The above remarks are intended for the benefit of those who may be engaged hereafter in similar experiments.

The results of these experiments are given in the following table: —

Table showing the pressure per square inch, due to the undermentioned weights of powder, when burned in the same space.

Weight of Charge.	Ratio of volume of Powder to that of the space in which it was burned.	1st Fire.	2d Fire.	3d Fire.	4th Fire.	5th Fire.	Mean.	REMARKS.
700 grs.	As 1 to 20	1000 lbs.	1000 lbs.	1200 lbs.	—	—	1066 lbs.	
737	19	1300	1200	1000	—	—	1166	
778	18	1300	1300	1350	—	—	1316	
821	17	1350	1350	1400	—	—	1367	
875	16	1400	1450	1500	—	—	1450	
933	15	1500	1500	1500	1500 lbs.	—	1500	Hazard's powder of 1857, proof range = 291 yards.
1000	14	1650	1650	1800	—	—	1700	
1077	13	1600	1650	1800	1800	1800 lbs.	1730	
1167	12	2100	2100	2100	2200	2200	2140	
1273	11	2100	2200	2350	2350	2350	2270	
1400	10	2350	2525	2525	2550	2675	2525	
1555	9	2600	2675	2700	2800	3100	2775	
1750	8	3600	3650	3650	3650	3650	3640	
2000	7	4200	4850	4200	4200	4200	4330	
2333	6	7300	5600	7300	7300	7300	6960	
2800	5	8000	8200	8200	—	—	8133	
3500	4	8750	8800	8750	—	—	8767	
4667	3	13600	13500	13600	—	—	13567	
7000	2	32500	32000	32100	—	—	32200	Dupont's, 1859, P. R.= 305 yards.
7000	2	42500	Shell burst.	—	—	—	42500	

The above results show that the pressure increases in a higher ratio than that of the volumes of powder; it being, for the larger charges, almost as the squares of the volumes.

And, as indicated by the 42-pdr. 9-inch and 11-inch guns, there is no doubt that, with a constant ratio of powder to the space in which it is burned, the pressure would increase with the charge of powder used; and it is deemed highly important to know in what ratio.*

These results, compared with those obtained from the 42-pdr. gun with 5.13 lbs. of powder, indicate that this charge was entirely consumed in that gun before the shot was 2 calibres from the bottom of the bore, and that the pressure was not truly indicated beyond 42 inches, or 6 calibres, in that gun.

They also show a marked difference in the quantities of gas evolved from equal weights of Hazard's and of Dupont's powder, the latter yielding the greater quantity.

They also show the effect of prolonging the time during which a given pressure acts; the 11-inch gun having endured 10 rounds, with a mean pressure of 86750 lbs. per inch, without bursting, while the shell $1\frac{1}{4}$ calibre thick, and of a better form to resist pressure, but on which the pressure was longer exerted, (the whole of the gas escaping through a 1-inch diameter orifice,) burst under a pressure of 42500 lbs. per inch.

The iron in the shell was of good quality, but there were some defects from cavities developed by the bursting which were not before discoverable, but not sufficient to account for the difference in endurance of the shell and gun above referred to.

It is believed that the most reliable tests for the relative volumes of gas evolved by equal volumes of different kinds of powder, and consequently of their relative merits, would be to determine the pressure due to the combustion of equal volumes, or equal weights of the different kinds of powder to be tested in the same space.

Pressure due to Unequal Volumes of Powder when Burned in Spaces bearing a Constant Ratio to those Volumes.

The foregoing experiments, taken in connection with those of the 42-pdr., 9-inch and 11-inch guns, where equal columns of powder were fired behind equal columns of metal, were thought to indicate that, with a constant ratio

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* Results at page 208 of this Report modify this conclusion.

of powder to the space in which it is burned, the pressure would increase with the mass of powder burned.

With a view to determine this point, four shells of different interior capacities were cast and prepared in the same manner as that used in the foregoing series, and shown in Plate 2.

The capacities of these shells were all accurately determined by filling them full of powder, while being struck with a heavy mallet, and then emptying them, and weighing their contents separately.

Each shell was then charged with one-fourth of the weight of powder which it had been thus found to contain, and fired; the pressure being determined by the method of indentations, the gas escaping at an orifice one-tenth of an inch in diameter. The shells were all carefully washed out with warm water, and well dried after each fire.

The following table exhibits the results obtained: —

Number OF Shells.	Weight of Charge.	PRESSURE OF GAS, IN POUNDS, PER SQUARE INCH.					
		1st Fire.	2d Fire.	3d Fire.	4th Fire.	5th Fire.	Mean.
1	1772 grs.	9248	9762	10019	8734	9248	9402
2	3610	10019	10276	9762	9248	8734	9608
3	5742	10019	8734	8734	8734	7707	8786
4	11817	9762	9762	10019	10019	10019	9916

These results indicate that where the volume of powder bears a constant ratio to the space in which it is burned, the pressure due to different masses of powder will be sensibly uniform, and consequently that they do not harmonize with the results obtained from the 42-pdr. 9-inch and 11-inch guns above referred to.

I am unable to assign any reason at all satisfactory to myself, in explanation of these *apparently* conflicting results; and, as the question is one of primary importance, it is believed that further experiments should be made, with a view to its proper and true solution.

Of the Absolute Pressure of Powder when burned in its own Volume.

The results at page 192, obtained from bursting cylinders of different thickness, with equal charges of powder, indicate, from the fact that those of .5 in. thick gave the same indications of pressure as those of 1 in. thick, that *time*

is required for the rupture of *any* mass of iron, though the rupturing force may be greatly in excess of the resistance of that mass; and that, by the method of indentations, the intensity of the bursting force may be registered before the rupture of the mass is accomplished.

Following these indications, it was thought that we might with *certainty* establish a higher inferior limit than has heretofore been *certainly* determined for the pressure due to the combustion of gunpowder in its own volume.

Accordingly, six shells, three of 12-inch and three of 13-inch exterior diameter, were cast and prepared for experiment. Those of 12-inch exterior diameter were intended to hold one pound of powder, and those of 13-inch, two pounds.

Fire was communicated to the powder through an orifice one-tenth of an inch in diameter, and this orifice was the only outlet for the gas. The pressure was determined by the method of indentations, as before described.

The shells were all filled full, being smartly rapped with a heavy mallet while the powder was being poured in, and their contents accurately determined by weight.

The results obtained are recorded in the following table : —

NUMBER OF SHELLS.	DIAMETERS OF SHELLS.		Contents of Shells.	Pressure of gas per square inch.	REMARKS.
	Interior.	Exterior.			
1	3.85 in.	12 in.	5910 grs.	185000 lbs.	In copper specimen.
2	3.85	12	6840	113040	In wrought iron specimen.
3	3.85	12	6560	107900	In wrought iron specimen.
4	4.85	13	9752	71932	In wrought iron specimen.
5	4.85	13	11250	100190	In wrought iron specimen.
6	4.85	13	14000	133590	In copper specimen.

The edges of the indentations in the wrought iron specimens were much more raised or "burred" than those made in copper, and much more, also, than those made by the testing machine in the same iron.

And it is believed that owing to this cause the machine indicates, with the iron specimens, a less pressure than was exerted by the gas. Iron was used instead of copper, for the reason that the pressure exerted at the first fire of this series forced the indenting tool into the copper specimen up to about the limit of its width, or indenting taper, and cut entirely across the specimen.

At the first fire the part of the housing that screwed into the shell pulled

out the metal of the shell into which it was screwed, the metal thus pulled out being broken, and not remaining attached to the housing.   This circumstance left it doubtful whether the housing had been detached from the shell before or at the time it burst, and consequently whether or not the full bursting pressure had been exerted upon the indenting piston.   In order to remove this doubt, the housing was, for the subsequent fires, screwed into the shells 2.5 in., instead of 1.5, the hold of that which pulled out, and no others pulled out; but all burst through the hole into which the housing was screwed.

This arrangement, however, increased by one inch the distance from the inner end of the indenting piston to the mouth of the housing; and this aperture, that in which the piston moves, being only .352 in. diameter, it is apprehended that the powder may have been so tightly packed into it before being ignited, as to prevent, by its friction, the full pressure on the interior of the shell from being exerted upon the indenting piston.

The friction of the gas check against the sides of the orifice in which it moves, prevents the full force of the gas from being exerted upon the indenting piston; and the more slowly applied pressure exerted by the machine than that exerted by the powder, ought to make an equal indentation with something less pressure; so that I should feel perfectly safe in fixing the inferior limit of the pressure per square inch, due to the combustion of gunpowder in its own volume, at, in round numbers, 200000 pounds.

Further experiments would render the results more certain; but would not, it is believed, reduce this estimate.

The powder used in these experiments was Dupont's, of 1859, .1 in. grain, procured for experimental purposes.

This series of experiments was made in March, 1860.

TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 in. long and 1.335 in. diameter, taken from near the surface of the bore of 42-pdr. gun, No. 336, cast hollow, at the Fort Pitt Foundry, of Bloomfield iron (No. 2 pig), and burst at the 491st round, with 10 lbs. powder, and one solid shot.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.000017	—	.000017	—	—	—
2000	.000038	.000021	.000038	.000021	—	—
3000	.000074	.000036	.000074	.000036	—	—
4000	.000131	.000057	.000131	.000057	—	—
5000	.000188	.000057	.000188	.000057	—	—
6000	.000246	.000058	.000243	.000055	.000003	—
7000	.000291	.000045	.000286	.000043	.000005	.000002
8000	.000366	.000075	.000358	.000072	.000008	.000003
9000	.000420	.000054	.000406	.000048	.000014	.000006
10000	.000502	.000082	.000479	.000073	.000023	.000009
11000	.000582	.000080	.000553	.000074	.000029	.000006
12000	.000666	.000084	.000623	.000070	.000043	.000014
13000	.000762	.000096	.000685	.000062	.000077	.000034
14000	.000882	.000120	.000768	.000083	.000114	.000037
15000	.001011	.000129	.000854	.000086	.000157	.000043
16000	.001140	.000129	.000926	.000072	.000214	.000057
17000	.001331	.000191	.001029	.000103	.000302	.000088
18000	.001528	.000197	.001106	.000077	.000422	.000120
19000	.001758	.000260	.001191	.000085	.000597	.000175
20000	.002160	.000372	.001317	.000126	.000843	.000246
21000	.002600	.000440	.001437	.000120	.001163	.000320
22000	.003217	.000617	.001557	.000120	.001660	.000497
23000	.004030	.000823	.001692	.000135	.002328	.000668
24000	.005128	.001098	.001757	.000065	.003371	.001043
25000	.006600	.001472	.001800	.000043	.004800	.001429
26000	Broke between 25000 and 26000 lbs., and failed to get ultimate extension.					

TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 in. long and 1.382 in. diameter, taken from near the middle of thickness of 42-pdr. gun, No. 336, cast hollow, at Fort Pitt Foundry, of Bloomfield iron, and burst at the 491st round, with 10 lbs. powder and one solid shot.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.000020	—	.000020	—	—	—
2000	.000070	.000050	.000070	.000050	—	—
3000	.000126	.000056	.000126	.000056	—	—
4000	.000176	.000050	.000172	.000046	.000004	—
5000	.000240	.000064	.000230	.000058	.000010	.000006
6000	.000322	.000082	.000306	.000076	.000016	.000006
7000	.000380	.000058	.000358	.000052	.000022	.000006
8000	.000450	.000070	.000428	.000070	.000022	.000000
9000	.000514	.000064	.000474	.000046	.000040	.000018
10000	.000590	.000076	.000530	.000056	.000060	.000020
11000	.000674	.000084	.000572	.000042	.000102	.000042
12000	.000776	.000102	.000654	.000082	.000122	.000020
13000	.000874	.000098	.000724	.000070	.000150	.000028
14000	.001000	.000126	.000792	.000068	.000208	.000058
15000	.001136	.000136	.000856	.000064	.000280	.000072
16000	.001304	.000168	.000942	.000086	.000362	.000082
17000	.001542	.000238	.001026	.000084	.000516	.000154
18000	.001800	.000258	.001086	.000060	.000714	.000198
19000	.002170	.000370	.001186	.000100	.000984	.000270
20000	.002714	.000544	.001320	.000134	.001394	.000410
21000	.003514	.000800	.001394	.000074	.002120	.000726
22000	.004542	.001028	.001478	.000034	.003064	.000944
23000	.005484	.000942	.001070	—.000408	.004414	.001350
24000	.006948	.001464	.000934	—.000036	.006014	.001600
25000	.011314	.004366	Broke between 24000 and 25000 lbs.			

TABLE *showing the extension, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 35 inches long and 1.382 in. diameter, taken from near the exterior surface of 42-pdr. gun, No. 336, cast hollow, at the Fort Pitt Foundry, of Bloomfield iron, and burst at the 491st round, with 10 lbs. powder and one solid shot.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.000026	—	.000026	—	—	—
2000	.000094	.000068	.000092	.000066	.000002	—
3000	.000148	.000054	.000142	.000050	.000006	.000004
4000	.000204	.000056	.000196	.000054	.000008	.000002
5000	.000260	.000056	.000250	.000054	.000010	.000002
6000	.000316	.000056	.000300	.000050	.000016	.000006
7000	.000380	.000074	.000360	.000060	.000020	.000004
8000	.000448	.000068	.000422	.000062	.000026	.000006
9000	.000522	.000074	.000488	.000066	.000034	.000008
10000	.000596	.000074	.000554	.000066	.000042	.000008
11000	.000674	.000078	.000594	.000040	.000080	.000038
12000	.000768	.000094	.000658	.000064	.000110	.000030
13000	.000886	.000118	.000736	.000078	.000150	.000040
14000	.001028	.000142	.000808	.000072	.000220	.000070
15000	.001176	.000148	.000868	.000060	.000308	.000088
16000	.001380	.000204	.000954	.000086	.000426	.000118
17000	.001670	.000290	.001042	.000088	.000628	.000202
18000	.001928	.000258	.001108	.000066	.000820	.000192
19000	.002556	.000628	.001254	.000146	.001302	.000482
20000	.003702	.001146	.001362	.000108	.002340	.001038
21000	.004160	.000458	.001410	.000048	.002750	.000410
22000	.005874	.001714	.001584	.000174	.004290	.001540
23000	.009102	.003228	.003142	.001558	.005960	.001670
24000	.009760	.000658	Broke between 23000 and 24000 lbs.			

TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder* 10 *in. long and* 1.382 *in. diameter, taken from near the surface of the bore of* 42-*pdr. gun, No.* 336, *cast hollow, at the Fort Pitt Foundry, of Bloomfield iron, and burst at the* 491*st round, with* 10 *lbs. powder and one solid shot.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00006	—	.00006	—	—	—
2000	.00010	.00004	.00010	.00004	—	—
3000	.00015	.00005	.00015	.00005	—	—
4000	.00021	.00006	.00021	.00006	—	—
5000	.00025	.00004	.00024	.00003	.00001	—
6000	.00031	.00006	.00030	.00006	.00001	.00000
7000	.00038	.00007	.00036	.00006	.00002	.00001
8000	.00046	.00008	.00043	.00007	.00003	.00001
9000	.00054	.00008	.00050	.00007	.00004	.00001
10000	.00062	.00008	.00056	.00006	.00006	.00002
11000	.00068	.00006	.00061	.00005	.00007	.00001
12000	.00076	.00008	.00067	.00006	.00009	.00002
13000	.00086	.00010	.00076	.00009	.00010	.00001
14000	.00092	.00006	.00080	.00004	.00012	.00002
15000	.00101	.00009	.00084	.00004	.00017	.00005
16000	.00108	.00007	.00088	.00004	.00020	.00003
17000	.00119	.00011	.00095	.00007	.00024	.00004
18000	.00129	.00010	.00099	.00004	.00030	.00006
19000	.00139	.00010	.00103	.00004	.00036	.00006
20000	.00150	.00011	.00107	.00004	.00043	.00007
21000	.00161	.00011	.00111	.00004	.00050	.00007
22000	.00172	.00011	.00117	.00006	.00055	.00005
23000	.00185	.00013	.00121	.00004	.00064	.00009
24000	.00200	.00015	.00124	.00003	.00076	.00012
25000	.00217	.00017	.00130	.00006	.00087	.00011
26000	.00237	.00020	.00133	.00003	.00104	.00017
27000	.00257	.00020	.00136	.00003	.00121	.00017
28000	.00283	.00026	.00141	.00005	.00142	.00021
29000	.00309	.00026	.00142	.00001	.00167	.00025
30000	.00342	.00033	.00140	—.00002	.00202	.00035
31000	.00389	.00047	.00147	+.00007	.00242	.00040
32000	.00426	.00037	.00143	—.00004	.00283	.00011
33000	.00495	.00069	.00156	+.00013	.00339	.00056
34000	.00576	.00081	.00166	.00010	.00410	.00071
35000	.00644	.00068	.00165	—.00001	.00479	.00069

TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder* 10 *inches long and* 1.382 *inches diameter, taken from near the middle of thickness of* 42-pdr. *gun, No.* 336, *cast hollow, at the Fort Pitt Foundry, of Bloomfield iron, and burst at the* 491st *round, with* 10 *lbs. powder and one solid shot.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00006	—	.00006	—	—	—
2000	.00011	.00005	.00011	.00005	—	—
3000	.00016	.00005	.00016	.00005	—	—
4000	.00020	.00004	.00019	.00003	.00001	—
5000	.00027	.00007	.00025	.00006	.00002	.00001
6000	.00034	.00007	.00032	.00007	.00002	.00000
7000	.00040	.00006	.00037	.00005	.00003	.00001
8000	.00047	.00007	.00043	.00006	.00004	.00001
9000	.00054	.00007	.00049	.00006	.00005	.00001
10000	.00066	.00012	.00060	.00011	.00006	.00001
11000	.00070	.00004	.00062	.00002	.00008	.00002
12000	.00079	.00009	.00070	.00008	.00009	.00001
13000	.00085	.00006	.00074	.00004	.00011	.00002
14000	.00093	.00008	.00079	.00005	.00014	.00003
15000	.00100	.00007	.00083	.00004	.00017	.00003
16000	.00109	.00009	.00089	.00006	.00020	.00003
17000	.00116	.00007	.00093	.00004	.00023	.00003
18000	.00125	.00009	.00098	.00005	.00027	.00004
19000	.00135	.00010	.00103	.00005	.00032	.00005
20000	.00144	.00009	.00107	.00004	.00037	.00005
21000	.00156	.00012	.00110	.00003	.00046	.00009
22000	.00163	.00013	.60116	.00006	.00053	.00007
23000	.00180	.00011	.00118	.00002	.00062	.00009
24000	.00194	.00014	.00122	.00004	.00072	.00010
25000	.00212	.00018	.00126	.00004	.00086	.00014
26000	.00232	.00020	.00130	.00004	.00102	.00016
27000	.00252	.00020	.00132	.00002	.00120	.00018
28000	.00286	.00034	.00139	.00007	.00147	.00027
29000	.00317	.00031	.00142	.00003	.00175	.00028
30000	.00357	.00040	.00147	.00005	.00210	.00035
31000	.00411	.00054	.00149	.00002	.00262	.00052
32000	.00493	.00082	.00154	.00005	.00339	.00077
33000	.00560	.00067	.00157	.00003	.00403	.00064
34000	.00682	.00122	.00209	.00052	.00473	.00070
35000	.00724	.00042	.00063	—.00146	.00661	.00188

TABLE *showing the compression, restoration, and permanent set per inch, in length, caused by the undermentioned weights, per square inch of section, acting upon a solid cylinder 10 inches long and 1.382 in. diameter, taken from near the exterior surface of 42-pdr. gun, No. 336, cast hollow, at the Fort Pitt Foundry, of Bloomfield iron, and burst at the 491st round, with 10 lbs. powder and one solid shot.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00006	—	.00006	—	—	—
2000	.00011	.00005	.00011	.00005	—	—
3000	.00016	.00005	.00016	.00005	—	—
4000	.00022	.00006	.00022	.00006	—	—
5000	.00027	.00005	.00026	.00004	.00001	—
6000	.00033	.00006	.00032	.00006	.00001	.00000
7000	.00038	.00005	.00036	.00004	.00002	.00001
8000	.00046	.00008	.00043	.00007	.00003	.00001
9000	.00053	.00007	.00049	.00006	.00004	.00001
10000	.00063	.00010	.00056	.00007	.00007	.00003
11000	.00069	.00006	.00059	.00003	.00010	.00003
12000	.00077	.00008	.00065	.00006	.00012	.00002
13000	.00086	.00009	.00072	.00007	.00014	.00002
14000	.00095	.00009	.00079	.00007	.00016	.00002
15000	.00103	.00008	.00082	.00003	.00021	.00005
16000	.00113	.00010	.00089	.00007	.00024	.00003
17000	.00122	.00009	.00094	.00005	.00028	.00004
18000	.00133	.00011	.00098	.00004	.00035	.00007
19000	.00143	.00010	.00106	.00008	.00037	.00002
20000	.00154	.00011	.00112	.00006	.00042	.00005
21000	.00167	.00013	.00118	.00006	.00049	.00007
22000	.00182	.00015	.00119	.00001	.00063	.00014
23000	.00200	.00018	.00125	.00006	.00075	.00012
24000	.00211	.00011	.00124	—.00001	.00087	.00012
25000	.00233	.00022	.00128	+.00004	.00105	.00018
26000	.00256	.00023	.00127	—.00001	.00129	.00024
27000	.00290	.00034	.00139	+.00012	.00151	.00022
28000	.00325	.00035	.00137	—.00002	.00188	.00037
29000	.00379	.00054	.00147	+.00010	.00232	.00044
30000	.00424	.00045	.00147	.00000	.00277	.00045
31000	.00486	.00062	.00147	.00000	.00339	.00062
32000	.00558	.00072	.00150	.00003	.00408	.00069
33000	.00646	.00088	.00074	—.00076	.00572	.00164

Specimen began to bend.

PLATE III.

Curves expressive of Extensibility, Compressibility and the corresponding Elasticity, and
Permanent set, of Inner, Middle and Outer Specimens from 42 pdr. Gun, No 336 Cast
hollow, at the Fort Pitt Foundry, of Bloomfield iron, and burst at the 491st fire, with
10 lbs. powder and one solid shot.
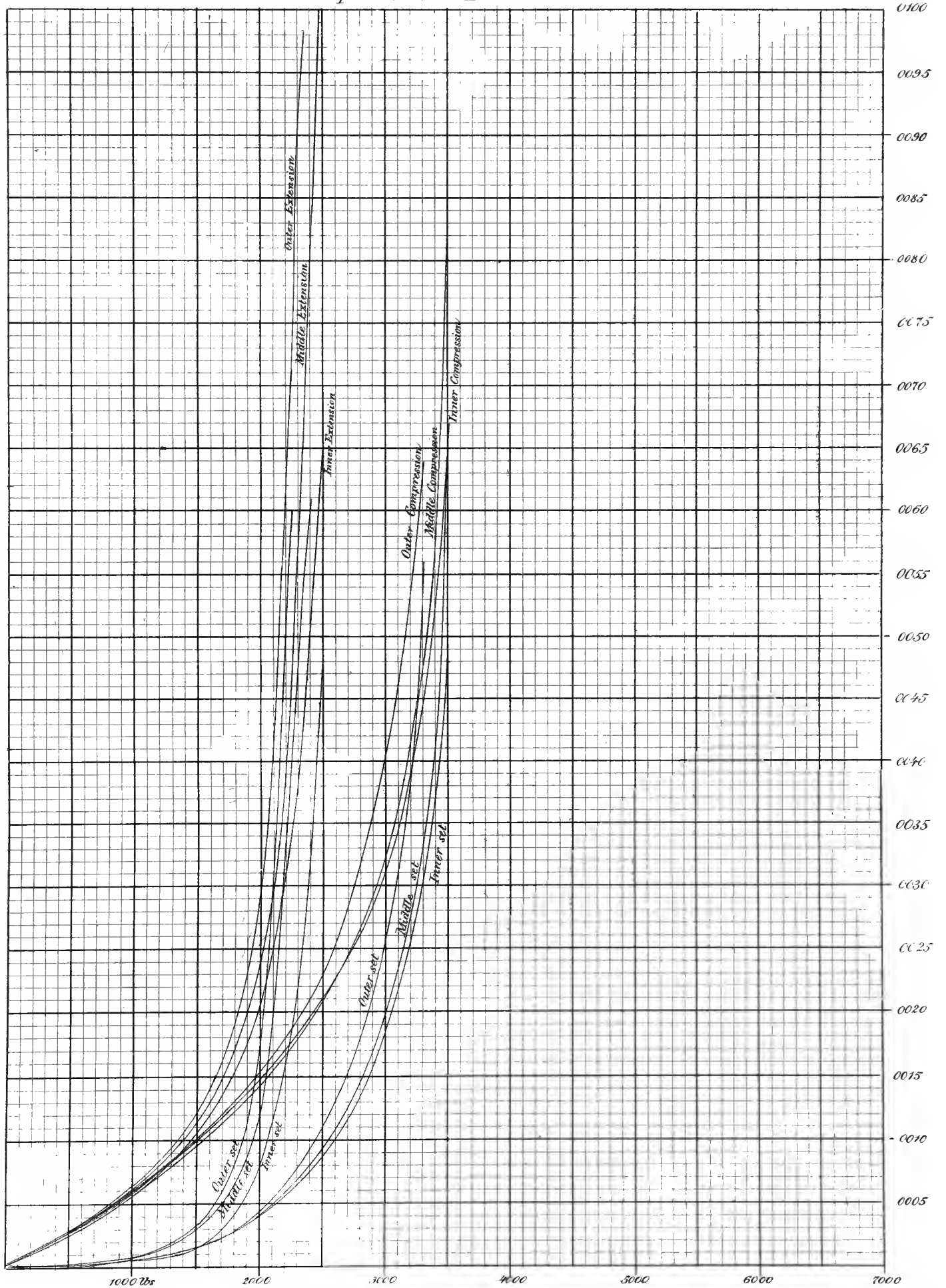
PLATE IV.

Curves comparing extensibility, permanent set, & elasticity of inner specimens, from
10 inch Columbiad Nº 983, of West Point Foundry, & 42 pdr. Nº 336, of Fort Pitt Foundry.
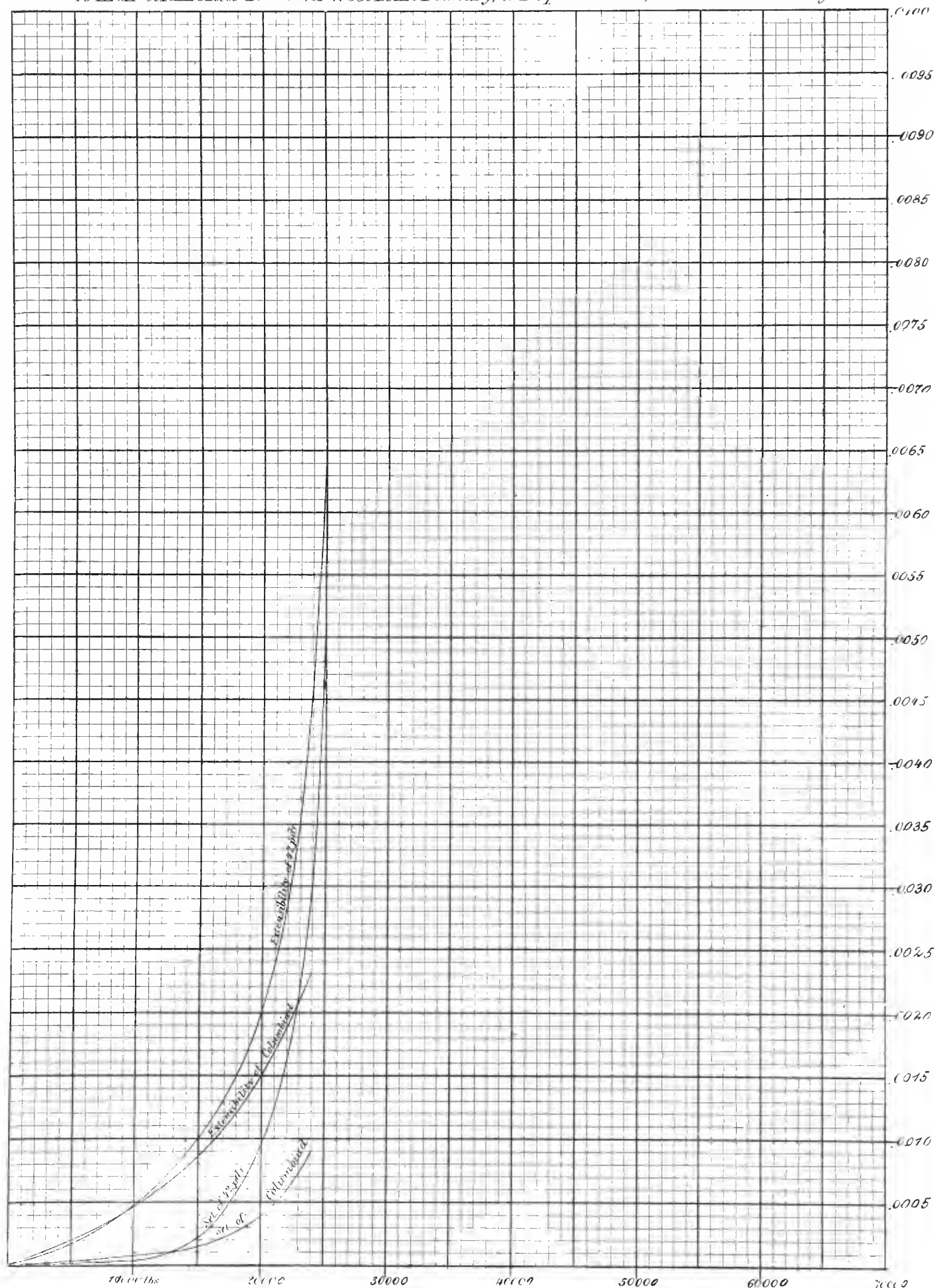
PLATE V

Curves comparing extensibility permanent set & elasticity of inner specimens from
10 inch Columbiad N°.335 & 12 pdr N°.336, both of the Fort Pitt Foundry

PLATE VI

Curves comparing compressibility, permanent set, & elasticity of inner specimens
from 10 inch Columbiad N.º 985, of West Point Foundry, & 42 pdr. N.º 336, of Fort Pitt Foundry.

.0100
.0095
.0090
.0085
.0080
.0075
.0070
.0065
.0060
.0055
.0050
.0045
.0040
.0035
.0030
.0025
.0020
.0015
.0010
.0005

Compressibility of 42 pdr.

Compressibility of Columbiad

Set of 42 pdr.

Columbiad

Set of

10000 lbs   20000   30000   40000   50000   60000   70000

PLATE VII.
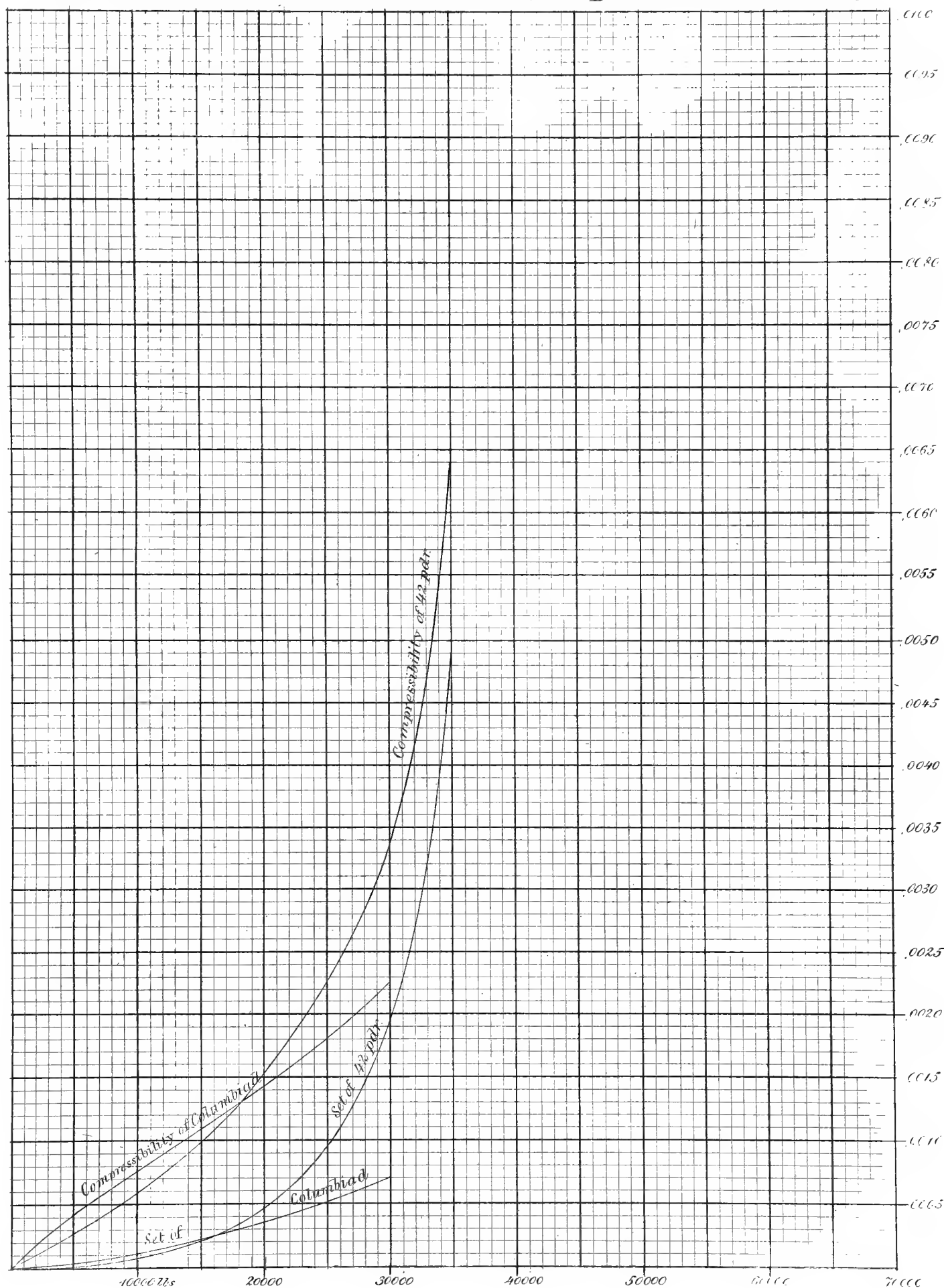
Curves comparing compressibility, permanent set & elasticity of inner specimens from 10 inch Columbiad Nº335 & 42 pdr. Nº336, both of Fort Pitt Foundry.

.0100

.0095

.0090

.00×5

.0080

.0075

.0070

.0065

.0060

.0055

.0050

.0045

.0040

.0035

.0030

.0025

.0020

.0015

.0010

.0005

Compty. of 42 pdr.

Set of 42 pdr.

Compressibility of Columbiad

Set of Columbiad

10000 lbs   20000   30000   40000   50000   60000   70000
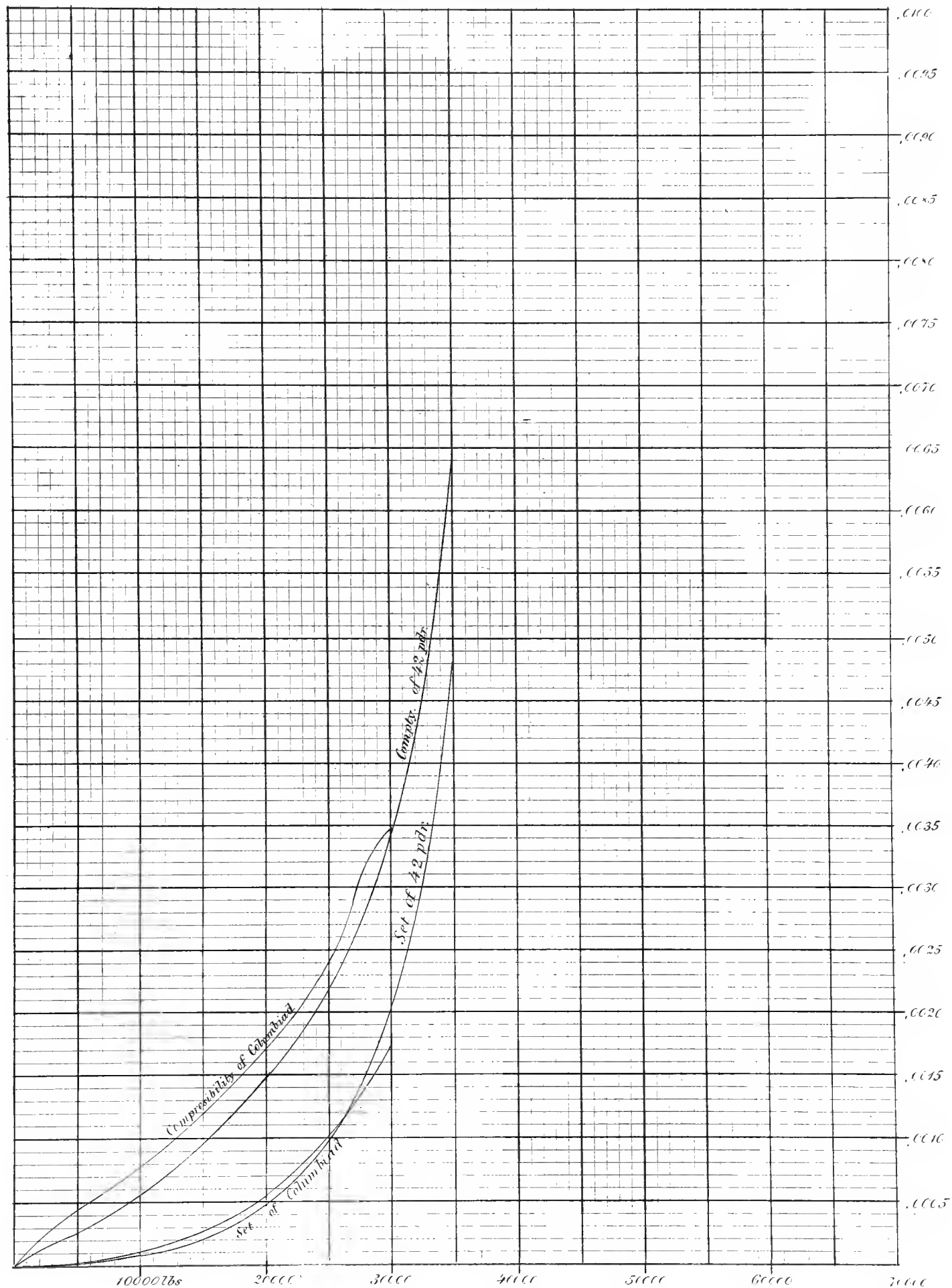
The foregoing results show remarkable extensibility; but the increments in extension due to equal increments of strain increase so rapidly towards the breaking weight, as greatly to impair this otherwise highly desirable quality. They also show too great compressibility, and not sufficient elasticity, in this iron, especially in returning from its compressed condition. This renders the effects of firing accumulative, and diminishes the work due to elasticity. This iron would doubtless be improved by further decarbonization.

Its ultimate extensibility would be diminished; but so also would its compressibility; while its tenacity and elasticity would both be increased. I think it highly desirable that this iron should be further tested, both with powder, and mechanically.

The curves expressive of the qualities of this iron (see Plates Nos. 3, 4, 5, 6, and 7,) show the inner specimen, which was most rapidly cooled, to be the best iron; and those comparing the qualities of this iron with those of that in the 10-inch guns, made mainly of Greenwood iron, show it to be intermediate, in quality, between the iron in those guns.

Determination of Exterior Model of Guns.

The formula for the bursting tendency,

$$Z = \frac{2\,p\,r\,R\,L}{S\,(R-r)\left(2\,r\,L + 3\,R\,(R+R)\,(R-r)\dfrac{l^4}{L^5}\right)},$$ becomes, by supposing

(Z) to remain constant, and R, L, and p, to vary, the equation of a portion of the curve of intersection of the exterior of one side of the gun by a plane containing the axis of the bore, since by this hypothesis the gun would be equally strong in all its parts.

In this formula (p) will obviously be a function of (L), and if we suppose the maximum pressure to be exerted upon a length (l') of the bore, and that the pressure from the forward extremity of (l') to the muzzle is inversely as the volume occupied by the gas, then the pressure at any distance (L) from the bottom of the bore, would be expressed by $\dfrac{p\,l'}{L}$, and the above formula would become, by changing (Z) to (C), and substituting for (p) its value $\left(\dfrac{p\,l'}{L}\right)$, $C = \dfrac{2\,p\,r\,l'}{S} \times \dfrac{R}{(R-r)\left(2\,r\,L + 3\,R\,(R+r)\,(R-r)\dfrac{l^4}{L^5}\right)}$.

Now since $\left(\dfrac{2\,p\,r\,l'}{S}\right)$ is constant, $\dfrac{R}{(R-r)\left(2\,r\,L + 3\,R\,(R+r)\,(R-r)\dfrac{l^4}{L^5}\right)}$

will also be constant; so that this last expression alone need be regarded in determining the value of (R) corresponding to the assumed values of (L).

From the great excess of the transverse over the tangential resistance for the smaller values of (L) and from the rapid diminution of the transverse resistance as (L) increases, the value of this expression, with a constant value of (R) will at first increase to a maximum, and then decrease as (L) increases. In order, therefore, to determine the proper exterior model of a gun, we first determine upon the volume of the charge; and, from the quality of the powder, and form and weight of projectile, the length of bore (l') subjected to the maximum pressure, and the value of that pressure.

Then establish the relation between (l') and (L) or the law of variation of pressure, and assume (l) equal to, or a little less, than two calibres, since experiment has shown the transverse resistance to be fully developed for about that length of surface pressed.

Then assume (R) equal to, or a little less than the greatest exterior radius of the gun, and determine the value of (L) that renders —

$$\frac{R}{(R-r)\left(2\,r\,L + 3\,R\,(R+r)\,(R-r)\,\dfrac{l^4}{L^5}\right)} \text{ a maximum.}$$

Then if (R) have been assumed equal to the greatest exterior radius, the gun will be cylindrical from this point back to the curve of the breech; and the curve of that portion forward of this point will be determined by assuming values for (L) and determining for (R) such corresponding values as will cause $\dfrac{R}{(R-r)\left(2\,r\,L + 3\,R\,(R+r)\,(R-r)\,\dfrac{l^4}{L^5}\right)}$ to remain constant, and equal to its maximum.

The accidental variations in the pressure produced by the irregularity of combustion of equal charges, are greater in that part of the bore subjected to the maximum pressure than in any other.

The quality of the metal is more liable to be injured by the greater pressure to which it is subjected, and by the greater consequent penetration of the gas into its pores, in this, than in any other part of the gun.

This portion of the gun is also under pressure for a greater length of time, at each discharge, than any other part. It should, therefore, have an excess of strength over other parts of the gun. And, since the tangential resistance increases very slowly as the thickness of metal increases beyond one calibre,

while the transverse resistance increases as the square of the thickness, in this part of the gun, this object will be accomplished with the minimum weight of metal, and a more pleasing outline given to the gun, by assuming (R), in determining that value of (L) which gives the maximum bursting tendency, from one-fifteenth to one-tenth less than the maximum exterior radius, and connecting the chase curve with that of the breech by another curve, such as to place the maximum diameter of the gun a little forward of the middle of the length of bore subjected to the maximum pressure, when firing the maximum charge.

The expression for the tangential resistance which enters the formula for the bursting tendency, was derived from the hypothesis that, in this resistance, the strain developed by the action of a central force in the concentric, elementary cylinders, of which we may suppose the gun to consist, diminishes as the square of the distance from the axis increases.

And although experiment has not, thus far, established the rigorous truth of this law, yet the results obtained from bursting cylinders with powder (see page 192) indicate that it would be unsafe to assume the strain to diminish in a less ratio.

And in guns made of very soft, and consequently highly compressible metal, I have no doubt that it may vary in even a higher ratio; and in solid cast guns, where the softest, most porous, and consequently most compressible iron in the gun is immediately around the bore, and of necessity subjected to the maximum pressure, the injurious effects of compressibility will reach their maximum.

Effects of Compressibility.

The effects of compressibility in gun iron, in diminishing both the transverse and the tangential resistance, have been already referred to. No definite expression, however, for the value or amount of those effects has yet been determined.

In order to determine this expression, let $(p) =$ pressure per square inch of gas on surface of bore, $c =$ compression per inch in length, due to (p), of a square prism one square inch in area of cross section, $(R) =$ exterior radius, $(r) =$ radius of bore, and $x =$ variable between R and r.

Then the elementary compression of this prism, due to (p) would $= c\,dx$; and if the pressure were uniform throughout the length of this prism, the integral of this expression would give its entire compression.

But, in a gun, the pressure per square inch against the interior of each consecutive, elementary cylinder of which we may suppose it to consist, will vary according to some regular law, which must first be determined.

For the purpose of determining this law, let us suppose a thin hollow cylinder, — a steam boiler for example, — and let (a) = tangential resistance per unit of length of one side of this boiler, (r') = interior radius, and (p') = pressure per square inch against its interior surface, which would just produce rupture. Then, from the well known formula for the strength of steam boilers, and for the bursting effort of any central force, we have $p'\, r' = a$ and consequently $p' = \dfrac{a}{r'}$. Or the pressure per square inch against the interior of a hollow cylinder, necessary to develop a constant amount of tangential resistance in its sides, is inversely as its interior radius.

The expression for the tangential resistance is $S\, \dfrac{(R\,r - r^2)}{R}$; hence $p\, r = S\, \dfrac{(R\,r - r^2)}{R}$, and $p = S\, \dfrac{(R\,r - r^2)}{R\,r}$.

The tangential resistance, developed in that portion of the gun whose interior radius is x, will be equal to the total tangential resistance minus that developed in that portion whose exterior radius $= x$; and consequently $= \left(S\, \dfrac{(R\,r - r^2)}{R} - S\, \dfrac{(x\,r - r^2)}{x} \right)$. Hence the pressure per square inch against the interior surface of the elementary cylinder whose interior radius $= x$ will be expressed by $\left(S\, \dfrac{(R\,r - r^2)}{R\,x} - S\, \dfrac{(x\,r - r^2)}{x^2} \right)$. And supposing the compression, per inch in length, of the same metal, to be directly proportional to the pressure per square inch, we shall have $p : c :: \left(S\, \dfrac{(R\,r - r^2)}{R\,x} - S\, \dfrac{(x\,r - r^2)}{x^2} \right) : y$; hence $y = \dfrac{S\,c}{p} \left(\dfrac{(R\,r - r^2)}{R\,x} - \dfrac{(x\,r - r^2)}{x^2} \right)$. And the elementary compression at any distance x from the axis, $= d\,u = \dfrac{S\,c}{p} \left(\dfrac{(R\,r - r^2)}{R\,x} - \dfrac{(x\,r - r^2)}{x^2} \right) d\,x$, and $u = \dfrac{S\,c}{p} \int \left(\dfrac{(R\,r - r^2)}{R} \dfrac{d\,x}{x} - \dfrac{r\,d\,x}{x} + \dfrac{r^2\,d\,x}{x^2} \right)$ $= \dfrac{S\,c}{p} \left(\dfrac{(R\,r - r^2)}{R} \text{ Nap. log. } x - r \text{ Nap. log. } x - \dfrac{r^2}{x} + C \right)$. But $u = 0$ when $x = r$; hence $C = \dfrac{S\,c}{p} \left(- \dfrac{(R\,r - r^2)}{R} \text{ Nap. log. } r + r \text{ Nap. log. } r + \dfrac{r^2}{r} \right)$ $= \dfrac{S\,c}{p} \left(\dfrac{(R\,r - R\,r + r^2)}{R} \text{ Nap. log. } r + r \right) = \dfrac{S\,c}{p} \left(\dfrac{r^2}{R} \text{ Nap. log. } r + r \right)$.

Hence $u = \dfrac{S\,c}{p}\left(\dfrac{R\,r - r^2}{R}\log. x - r\log. x - \dfrac{r^2}{x} + \dfrac{r^2}{R}\log. r + r\right)$

$= \dfrac{Sc}{p}\left(\dfrac{R\,r - r^2 - R\,r}{R}\log. x - \dfrac{r^2}{x} + \dfrac{r^2}{R}\log. r + r\right) = \dfrac{S\,c}{p}\left(\dfrac{r^2}{R}\log.\dfrac{r}{x} - \dfrac{r^2}{x} + r\right).$

And integrating between the limits $x = r$, and $x = R$, we have, since $u = 0$

when $x = r$, $u = \dfrac{S\,c}{p}\left(\dfrac{r^2}{R}\log.\dfrac{r}{R} - \dfrac{r^2}{R} + r\right)$; and if the gun be one calibre

thick, R will $= 3\,r$, and we shall have, by substituting this value of R,

$u = \dfrac{S\,c}{p}\left(\dfrac{r}{3}\text{ Nap. log. }\dfrac{1}{3} - \dfrac{r}{3} + r\right) = \dfrac{S\,c}{p}\left(\dfrac{r}{3}\text{ Nap. log. }\dfrac{1}{3} + \dfrac{2\,r}{3}\right)$.   And

since the log. of $1 = 0$, we have $u = \dfrac{S\,c}{p}\left(\dfrac{2\,r}{3} - \dfrac{r}{3}\text{ Nap. log. }3\right)$.   But the

Nap. log. $3 = 1.0986$.

Assuming this log. $= 1$, we have $u = \dfrac{S\,c}{p}\times\dfrac{r}{3}$.   Now supposing $p = S$,

or that the pressure per square inch on the bore of the gun is equal to the

tensile strength of the metal, we have $u = c\,\dfrac{r}{3}$; or the increase in diameter

of the bore, due to the compression of the metal, in a gun one calibre thick,
is equal to one-third of the total compression which a prism, whose height
equals the diameter of the bore, would undergo under a pressure per square
inch equal to that against the bore of the gun.

Now, if we suppose a given pressure to be exerted upon the surface of the
bore of a gun, while its exterior diameter is prevented from undergoing any
increment, the total enlargement of the bore, and the consequent extension
of the metal, will be wholly due to compression, and all the effects of com-
pression will be produced, as if the exterior of the gun were unconstrained.

If we now suppose the exterior restraint removed, the interior and
exterior diameters would undergo precisely equal increments.   Or the gun
would expand in the same manner as one of which the metal is perfectly
incompressible, the metal having already undergone all the compression
which this pressure could produce ; and the extension of the metal at the
two surfaces of the gun, which would take place after the removal of the
exterior restraint, would therefore be inversely as their radii.

It has just been shown that in a gun one calibre thick the total enlarge-

ment of the bore, due to compression, $= \dfrac{2\,r\,c}{3}$; the total extension at the

surface of the bore, due to this enlargement, $= 2\,\pi\,r\,\dfrac{c}{3}$; and the extension

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per inch at the same surface $= \dfrac{2 \pi r \frac{c}{3}}{2 \pi r} = \dfrac{c}{3}$.   Now if $a =$ the total exten-sion per inch of which the metal is susceptible, then $a - \dfrac{c}{3} =$ the extension per inch which the surface of the bore underwent after the removal of the exterior restraint, and the extension per inch of the exterior surface would

$$= \dfrac{a - \dfrac{c}{3}}{3} = \dfrac{3\,a - c}{9}.$$

To exemplify, let us take cylinder A, O., (see page 227,) the total exten-sion per inch of which, was .00303, the compression per inch of A, T. was .00441, one-third of which $=$ .00147, and .00303 $-$ .00147 $=$ .00156, one-third of which $=$ .00052 $=$ the extension per inch of the exterior of a gun, one calibre thick, made of this metal, at the moment of interior rupture.

By reference to the column of extension of A, O., it will be seen that 11000 lbs. per inch were required to produce an extension of .00054; or the exterior of the gun would be under a strain of between 10000 and 11000 lbs. per inch at the moment of interior rupture; while, if the metal were perfectly incompressible, it would at the same moment be under a strain of 18000 lbs.

The expression $r\,\dfrac{c}{3}$ was derived from the hypothesis that the compression per inch of cast iron is directly proportional to the pressure, — experiment shows the compression of this metal to increase in a higher ratio; so that the effects of compressibility will be something greater than those just deter-mined.

These examples suffice to establish the importance attaching to the prop-erty of compressibility in gun metal, its action being to prevent the full development of both the transverse and the tangential resistance, and to that degree, it is believed, in guns of large calibre, and consequently of great pressure of gas, as to cause interior, longitudinal rupture before the trans-verse resistance is fully developed, even for the shortest practical lengths of surface pressed.

For this reason only one-third of the theoretical transverse resistance was used in computing the exterior radii of the 15-inch gun; the formula used for this computation being,

$$C = \dfrac{2\,p\,r\,\sqrt{l'}}{S} \times \dfrac{R\,\sqrt{L}}{(R-r)\left(2\,r\,L + R\,(R+r)\,(R-r)\,\dfrac{l^4}{L^5}\right)}.$$

PLATE VIII.

Scale 1/24 Size
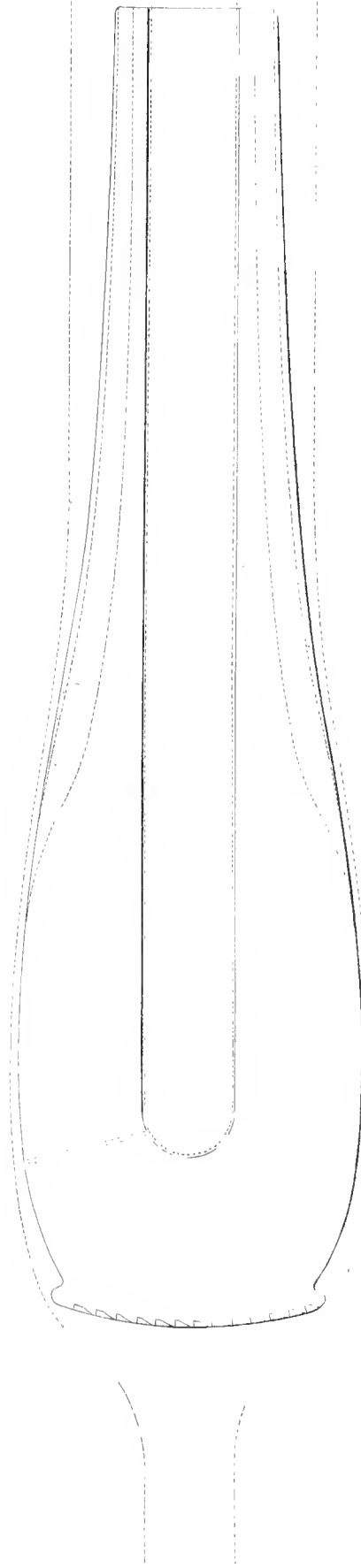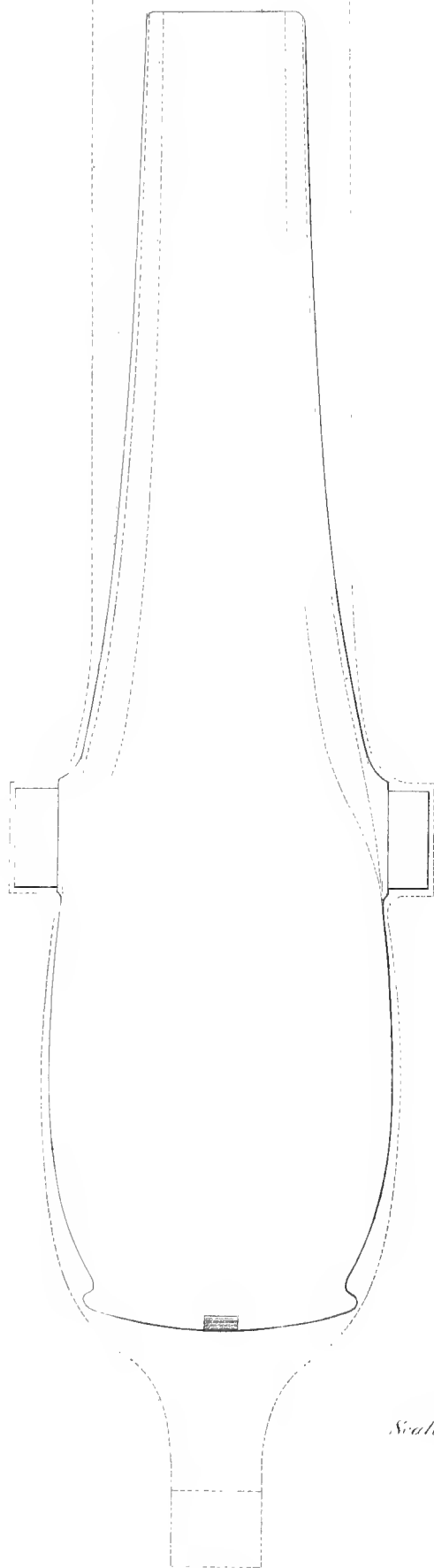
The value of R, used in determining the value of (L), which rendered the bursting tendency a maximum, was $= 22.5$ inches.

The outer and extreme inner dotted lines in the figure on Plate 8, give the exterior form and proportions, and diameter of bore, of the gun as cast. The inner *curved* dotted lines, on the same figure, give the form and proportions of a gun of the same bore and maximum exterior diameter, computed on the hypothesis that the pressure of the gas is inversely as the space behind the shot. The middle dotted lines, same figure, give the form and proportions of a gun of the same diameter of bore and maximum exterior diameter, on the hypothesis that the pressure is inversely as the square root of the space behind the shot, or as $\sqrt{L}$.

The full lines, same figure, show the form and proportions of this gun, as finished, on a scale of one-twentieth size.

It will be observed that this gun is something heavier in the chase, than the hypothesis, that the pressure is inversely as $\sqrt{L}$, would give it. It was purposely made so; for the reason that it was intended to use charges of such character as would produce a much more uniform pressure, and consequently, greater pressure, in the chase of the gun, for a given maximum pressure, than is obtained by the use of ordinary powder.

It should be here remarked that, even for guns in which a quick powder is to be used, the lines due to the law that the pressure is inversely as (L), should not be strictly adhered to in that part where the most rapid diminution of exterior diameter occurs; for the reason that, in so doing, the front ends of the staves, for those lengths of bore subjected to the greatest pressure, would be deprived of their proper support, and the transverse resistance would be greatly diminished just where it is most needed, and where its value is greatest in the properly modelled gun.

The beginning of the taper should therefore be, say half a calibre further forward, and the taper made less rapid than the law of pressure, in this part of the gun, would give it.

Experiment has not yet satisfactorily established the law of variation in pressure due to the ordinary cannon powder. But it is considered that no powder is fit for use in guns of large calibre, that will not so far approximate to uniformity of pressure as to conform to the law that the pressure is inversely as $\sqrt{L}$.

It requires time for the development of high velocities in large masses;

consequently heavy projectiles require longer guns and a slower burning powder, that will produce a more nearly equal pressure in the different parts of the bore, than are now in use. And the material of which large guns are at present made imperatively demands the same conditions; for unless they be fulfilled, we must be content with low velocities and low endurance, and in constant danger from the bursting of our own guns.

Termination of Bore.

The most suitable form for the termination of the bore of a gun has not yet been established by direct experiment. It has been customary, in guns of large calibre, to terminate the bore in a chamber of smaller diameter than the bore, and of such length as to contain the charge of powder. But for reasons given in my Report of 1857, (pages 48 and 49,) and from the greater endurance of guns of the same calibre *without* than of those *with* chambers, it appears highly probable that the endurance of a gun is diminished by the use of the chamber.

Had the more durable guns differed from the less in no other point than in the absence of the chamber, all doubt on the subject would have been removed; but they did differ, not only in exterior model, but also in a greatly increased thickness of metal in the breech—so that this point is still uncertain, and should be determined by direct experiment.

In the absence, however, of what is properly called a chamber, the termination of the bore admits of considerable variation.

If the bore should terminate in a plane bottom, as in Fig. *A*, rupture would

Fig. *A.*
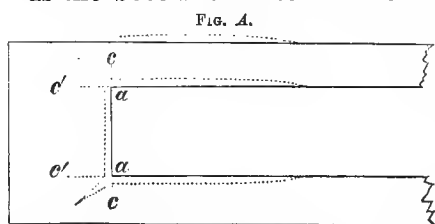
be most likely to occur at the junction of the bottom and sides of the bore, for the double reason that the staves would, by being bent out, tend to break off at that line, and because the motion due to compressibility of the metal would tend to move the particles contiguous to that line in two directions, *a c*, and *a c′*, at right angles to each other, at the same time, which could not occur without rupture. Both of these causes of rupture are at their maximum when the bore terminates in a plane, which consequently is the worst termination.

They both diminish as the radius of curvature of the surface joining the sides and bottom of the bore increases, that from the compressibility of the

metal being a minimum when that radius = that of the bore, or when the bore terminates in a hemisphere.

The tendency to rupture from the bending of the staves outward would be still further diminished by terminating the bore in a semi-ellipsoid, whose major axis should coincide with that of the bore of the gun.

There should be no angles, either salient or re-entrant, in the termination of the bore, but the surfaces of the bore and of its termination should be tangent along their line of junction.

The hemisphere and the semi-ellipsoid are the two regular geometrical figures which fulfil these conditions; and since the tendency to rupture from the outward bending of the staves would, it is believed, diminish more rapidly than that from the compressibility of the metal would increase, while near its minimum the semi-ellipsoid is believed to be the best and true termination.

The termination of the bore should not be longer than may be necessary to hold the service charge; for any greater length would increase the length of bore subjected to the maximum pressure, which should not be done, if it can be avoided, without encountering greater danger.

From these considerations, the bore of the 15-inch gun was terminated by a semi-ellipsoid, with a major axis of 18 inches.

Preliminary Castings for 15-inch Gun.

With a view to determine the proper quality of iron for casting into a 15-inch gun, the following castings were made, viz. :—

A right cylinder, marked (A), 60 inches high, with an elliptical base, of which the transverse axis was 24 in. and the conjugate 16.5 in., made of 2d fusion Bloomfield iron.

Also another cylinder, marked (B), and moulded on the same pattern, from the following composition, viz. :—

Of 2d fusion iron (made of 4 parts No. 1, 7 parts
    No. 2, and 4 parts No. 3, Greenwood pig),   .   2455 lbs.
Of No. 1 Greenwood pig, ...   613
    "   2   "   "   1227
    "   3   "   "   613
Of Salisbury pig, ...   1090

      Total, ...   5998 lbs.

57

Also another cylinder, marked (*C,*) off the same pattern, and composed entirely of 2d fusion pigs, consisting of equal parts of Greenwood and Bloomfield iron.

Also another cylinder, marked (*D,*) and composed as follows, viz. : Greenwood and Salisbury pigs were melted together in the following proportions, viz. :—

No. 1 Greenwood, ...	1093 lbs.
" 2 "	1914
" 3 "	1093
Salisbury pigs, ...	900
Total, ...	5000 lbs.

Being 82 per cent. of Greenwood and 18 per cent. of Salisbury iron, which was cast into 2d fusion pigs. From these 2d fusion pigs cylinder (*D,*) was cast.

From each of these cylinders a slab 4.5 in. thick was cut, by planes parallel to and equi-distant from the plane containing the axis of the cylinder and the conjugate axis of its base.

Specimens were taken from like parts of each of these slabs, and subjected to similar tests.

The accompanying drawing (Plate No. 9,) shows the position whence the specimens for the various tests were taken, and the following tables exhibit the results obtained :—

PLATE IX.

EXTENSION OF **A**, O.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder* 30 *in. long and* 1.382 *in. diameter, cut from exterior of trial cylinder* (**A**), *made of* 2d *fusion Bloomfield iron.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00002	–	.00002	–	–	–
2000	.00004	.00002	.00004	.00002	–	–
3000	.00013	.00009	.00013	.00009	–	–
4000	.00019	.00006	.00019	.00006	–	–
5000	.00023	.00004	.00023	.00004	–	–
6000	.00027	.00004	.00027	.00004	–	–
7000	.00033	.00006	.00033	.00006	–	–
8000	.00037	.00004	.00037	.00004	–	–
9000	.00043	.00006	.00042	.00005	.00001	–
10000	.00049	.00006	.00047	.00005	.00002	.00001
11000	.00054	.00005	.00052	.00005	.00002	.00000
12000	.00060	.00006	.00057	.00005	.00003	.00001
13000	.00066	.00006	.00062	.00005	.00004	.00001
14000	.00073	.00007	.00067	.00005	.00006	.00002
15000	.00080	.00007	.00073	.00006	.00007	.00001
16000	.00087	.00007	.00078	.00005	.00009	.00002
17000	.00095	.00008	.00084	.00006	.00011	.00002
18000	.00103	.00008	.00089	.00005	.00014	.00003
19000	.00112	.00009	.00096	.00007	.00016	.00002
20000	.00122	.00010	.00103	.00007	.00019	.00003
21000	.00133	.00011	.00110	.00007	.00023	.00004
22000	.00144	.00011	.00116	.00006	.00028	.00005
23000	.00159	.00015	.00123	.00007	.00036	.00008
24000	.00173	.00014	.00130	.00007	.00043	.00007
25000	.00191	.00018	.00138	.00008	.00053	.00010
26000	.00210	.00019	.00145	.00007	.00065	.00012
27000	.00237	.00027	.00153	.00008	.00084	.00019
28000	.00267	.00030	.00163	.00010	.00104	.00020
29000	.00303	.00036	.00179	.00009	.00131	.00027
30000	Broke between 29000 and 30000 lbs.					

EXTENSION OF **A**, I.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder 30 in. long and 1.382 in. diameter, cut from near the axis of trial cylinder* (**A**), *made of 2d fusion Bloomfield iron.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00003	—	.00003	—	—	—
2000	.00007	.00004	.00007	.00004	—	—
3000	.00011	.00004	.00011	.00004	—	—
4000	.00016	.00005	.00016	.00005	—	—
5000	.00021	.00005	.00021	.00005	—	—
6000	.00026	.00005	.00026	.00005	—	—
7000	.00029	.00003	.00029	.00003	—	—
8000	.00035	.00006	.00034	.00005	.00001	—
9000	.00039	.00004	.00038	.00004	.00001	.00000
10000	.00050	.00011	.00047	.00009	.00003	.00002
11000	.00057	.00007	.00053	.00006	.00004	.00001
12000	.00064	.00007	.00059	.00006	.00005	.00001
13000	.00071	.00007	.00065	.00006	.00006	.00001
14000	.00079	.00008	.00072	.00007	.00007	.00001
15000	.00087	.00008	.00079	.00007	.00008	.00001
16000	.00096	.00009	.00085	.00006	.00011	.00003
17000	.00105	.00009	.00091	.00006	.00014	.00003
18000	.00115	.00010	.00097	.00006	.00018	.00004
19000	.00129	.00014	.00108	.00011	.00021	.00003
20000	.00142	.00013	.00115	.00007	.00027	.00006
21000	.00159	.00017	.00124	.00009	.00035	.00008
22000	.00175	.00016	.00131	.00007	.00044	.00009
23000	.00193	.00018	.00138	.00007	.00055	.00011
24000	.00217	.00024	.00147	.00009	.00070	.00015
25000	.00245	.00028	.00156	.00009	.00089	.00019
26000	.00277	.00032	.00163	.00007	.00114	.00025
27000	.00334	.00057	—	—	—	—

REPETITIONS OF **A**, O.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the repeated application of 22000 lbs. (or three-quarters of breaking weight) per square inch, on a solid cylinder 30 in. long and 1.382 in. diameter, cut from exterior of trial cylinder* (**A**)*, made of 2d fusion Bloomfield iron.*

Number of repetitions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1	.00150	—	.00118	—	.00032	—
10	.00153	.00003	.00116	— 00002	.00037	.00005
50	.00183	.00030	.00122	+.00006	.00061	.00024
100	.00183	.00000	.00119	—.00003	.00064	.00003
150	.00183	.00000	.00118	—.00001	.00065	.00001
200	.00185	.00002	.00117	—.00001	.00068	.00003
300	.00187	.00002	.00119	+.00002	.00068	.00000
400	.00188	.00001	.00119	.00000	.00069	.00001
500	.00189	.00001	.00120	+.00001	.00069	.00000
600	.00189	.00000	.00119	—.00001	.00070	.00001
700	.00189	.00000	.00119	.00000	.00070	.00000
800	.00190	.00001	.00119	.00000	.00071	.00001
After 14 hrs. rest.						
801	.00189	—	.00116	—	.00069	—
900	.00191	.00002	.00120	.00004	.00071	.00002
1000	.00191	.00000	.00120	.00000	.00071	.00000
1200	.00192	.00001	.00119	—.00001	.00073	.00002
1400	.00194	.00002	.00120	+.00001	.00074	.00001
After 36 hrs. rest.						
1401	.00193	—	.00122	—	.00071	—
1600	.00195	.00002	.00121	—.00001	.00074	.00003
1735	.00196	.00001	.00122	+.00001	.00074	.00000
1800	.00197	.00001	.00123	.00001	.00074	.00000
2000	.00197	.00000	.00123	.00000	.00074	.00000
2100	.00198	.00001	.00123	.00000	.00075	.00001
2300	.00198	.00000	.00123	.00000	.00075	.00000
Broke at 2301st application—head pulled off.						
Mean, . .	. . . .	. . . .	.00120			

REPETITIONS OF A, O. — (Duplicate.)

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the repeated application of* 26000 *lbs. (or .9 of breaking weight) per square inch, on a solid cylinder* 30 *in. long and* 1.382 *in. diameter, cut from exterior of trial cylinder* (**A**), *made of 2d fusion Bloomfield iron.*

Number of repetitions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1	.00221	—	.00157	—	.00064	—
10	.00223	.00007	.00155	—.00002	.00073	.00009
30	.00242	.00014	.00156	+.00001	.00086	.00013
50	.00249	.00007	.00156	.00000	.00093	.00007
70	.00253	.00004	.00156	.00000	.00097	.00004
100	.00263	.00010	.00157	.00001	.00106	.00009
150	.00274	.00011	.00159	.00002	.00115	.00009
200	.00277	.00003	.00156	—.00003	.00121	.00006
250	.00292	.00015	.00164	+.00008	.00128	.00007
281	Broke at the 282d repetition.					
Mean, . .	. . . . .	. . . .	.00157			

EXTENSION OF **B**, O.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder 30 in. long and 1.382 in. diameter, cut from exterior of trial cylinder* (**B**), *made of Greenwood and Salisbury iron.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00003	—	.00003	—	—	—
2000	.00008	.00005	.00008	.00005	—	—
3000	.00013	.00005	.00013	.00005	—	—
4000	.00018	.00005	.00018	.00005	—	—
5000	.00024	.00006	.00024	.00006	—	—
6000	.00030	.00006	.00030	.00006	—	—
7000	.00035	.00005	.00034	.00004	.00001	—
8000	.00042	.00007	.00041	.00007	.00001	.00000
9000	.00048	.00006	.00046	.00005	.00002	.00001
10000	.00056	.00008	.00052	.00006	.00004	.00002
11000	.00065	.00009	.00060	.00008	.00005	.00001
12000	.00074	.00009	.00067	.00007	.00007	.00002
13000	.00083	.00009	.00074	.00007	.00009	.00002
14000	.00093	.00010	.00080	.00006	.00013	.00004
15000	.00108	.00015	.00090	.00010	.00018	.00005
16000	.00122	.00014	.00098	00008	.00024	.00006
17000	.00140	.00018	.00106	.00008	.00034	.00010
18000	.00160	.00020	.00115	.00009	.00045	.00011
19000	.00191	.00031	.00131	.00016	.00060	.00015
20000	.00235	.00044	.00140	.00009	.00095	.00035
21000	.00291	.00056	.00154	.00014	.00137	.00042
22000	Broke between 21000 and 22000 lbs.					

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EXTENSION OF **B**, I.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder 30 in. long and 1.382 in. diameter, cut from near the axis of trial cylinder (**B**), made of Greenwood and Salisbury iron.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00005	—	.00005	—	—	—
2000	.00010	.00005	.00010	.00005	—	—
3000	.00015	.00005	.00015	.00005	—	—
4000	.00020	.00005	.00020	.00005	—	—
5000	.00024	.00004	.00023	.00003	.00001	—
6000	.00031	.00007	.00029	.00006	.00002	.00001
7000	.00041	.00010	.00039	.00010	.00002	.00000
8000	.00052	.00011	.00049	.00010	.00003	.00001
9000	.00059	.00007	.00055	.00006	.00004	.00001
10000	.00070	.00011	.00065	.00010	.00005	.00001
11000	.00081	.00011	.00072	.00007	.00009	.00004
12000	.00091	.00010	.00078	.00006	.00013	.00004
13000	.00105	.00014	.00086	.00008	.00019	.00006
14000	.00119	.00014	.00094	.00008	.00025	.00006
15000	.00139	.00020	.00104	.00010	.00035	.00010
16000	.00161	.00022	.00112	.00008	.00049	.00014
17000	Broke between 16000 and 17000 lbs.					

REPETITIONS OF **B**, O.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the repeated application of 20000 lbs. (or .9 of breaking weight) per square inch, on a solid cylinder 30 in. long and 1.382 in. diameter, cut from the exterior of trial cylinder (**B**), made of Greenwood and Salisbury iron.*

Number of repetitions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1	.00278	—	.00135	—	.00143	—
10	.00295	.00017	.00134	—.00001	.00159	.00016
30	.00320	.00025	.00131	—.00003	.00189	.00030
After 12 hrs. rest.						
31	.00324	—	.00135	—	.00189	—
40	.00333	.00009	.00137	+.00002	.00196	.00007
50	.00338	.00005	.00133	—.00004	.00205	.00009
70	.00353	.00015	.00141	+.00008	.00212	.00007
100	.00362	.00009	.00140	—.00001	.00222	.00010
150	.00373	.00011	.00140	.00000	.00233	.00011
200	.00382	.00009	.00139	—.00001	.00243	.00010
251	.00392	.00010	.00137	—.00002	.00255	.00012
Mean, . .	. . . . .	. . . . .	.00137			

REPETITIONS OF **B**, O. —(DUPLICATE.)

With 20000 *lbs. per inch.*

Number of repetitions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1	.00218	—	.00128	—	.00090	—
10	.00246	.00028	.00134	.00006	.00112	.00022
30	.00270	.00024	.00136	.00002	.00134	.00022
50	.00292	.00022	.00135	—.00001	.00157	.00023
70	.00309	.00017	.00143	+.00008	.00166	.00009
100	.00323	.00014	.00149	.00006	.00174	.00008
150	Broke at the 150th repetition.					
Mean, . .	. . . . .	. . . . .	.00138			

EXTENSION OF **C**, O.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder 30 in. long and 1.382 in. diameter, cut from exterior of trial cylinder* (**C**), *made from equal parts of 2d fusion Greenwood and Bloomfield iron.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00004	—	.00004	—	—	—
2000	.00008	.00004	.00008	.00004	—	—
3000	.00012	.00004	.00012	.00004	—	—
4000	.00018	.00006	.00018	.00006	—	—
5000	.00022	.00004	.00021	.00003	.00001	—
6000	.00027	.00005	.00026	.00005	.00001	.00000
7000	.00032	.00005	.00030	.00004	.00002	.00001
8000	.00041	.00009	.00039	.00009	.00002	.00000
9000	.00046	.00005	.00043	.00004	.00003	.00001
10000	.00052	.00006	.00048	.00005	.00004	.00001
11000	.00059	.00007	.00054	.00006	.00005	.00001
12000	.00066	.00007	.00060	.00006	.00006	.00001
13000	.00075	.00009	.00067	.00007	.00008	.00002
14000	.00083	.00008	.00074	.00007	.00009	.00001
15000	.00093	.00010	.00081	.00007	.00012	.00003
16000	.00102	.00009	.00086	.00005	.00016	.00004
17000	.00114	.00012	.00094	.00008	.00020	.00004
18000	.00127	.00013	.00102	.00012	.00021	.00001
19000	.00141	.00014	.00110	.00004	.00031	.00010
20000	.00156	.00015	.00118	.00008	.00038	.00007
21000	.00173	.00017	.00125	.00007	.00048	.00010
22000	.00196	.00023	.00135	.00010	.00061	.00013
23000	.00221	.00025	.00144	.00009	.00077	.00016
24000	.00252	.00031	.00153	.00009	.00099	.00022
25000	.00287	.00035	.00160	.00007	.00127	.00023
26000	Broke between 25000 and 26000 lbs.					

EXTENSION OF **C**, I.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder 30 in. long and 1.382 in. diameter, cut from near the axis of trial cylinder (**C**), made from equal parts of 2d fusion Greenwood and Bloomfield iron.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00004	—	.00004	—	—	—
2000	.00008	.00004	.00008	.00004	—	—
3000	.00012	.00004	.00012	.00004	—	—
4000	.00018	.00006	.00018	.00006	—	—
5000	.00022	.00004	.00022	.00004	—	—
6000	.00027	.00005	.00026	.00004	.00001	—
7000	.00033	.00006	.00032	.00006	.00001	.00000
8000	.00038	.00005	.00036	.00004	.00002	.00001
9000	.00045	.00007	.00043	.00007	.00002	.00000
10000	.00051	.00006	.00048	.00005	.00003	.00001
11000	.00058	.00007	.00054	.00006	.00004	.00001
12000	.00065	.00007	.00060	.00006	.00005	.00001
13000	.00073	.00008	.00066	.00006	.00007	.00002
14000	.00081	.00008	.00072	.00006	.00009	.00002
15000	.00091	.00010	.00080	.00008	.00011	.00002
16000	.00099	.00008	.00085	.00005	.00014	.00003
17000	.00109	.00010	.00092	.00007	.00017	.00003
18000	.00120	.00011	.00098	.00006	.00022	.00005
19000	.00133	.00013	.00106	.00008	.00027	.00005
20000	.00147	.00014	.00114	.00008	.00033	.00006
21000	.00163	.00016	.00122	.00008	.00041	.00008
22000	.00183	.00020	.00131	.00009	.00052	.00011
23000	.00207	.00024	.00137	.00006	.00070	.00018
24000	.00232	.00025	.00146	.00019	.00086	.00016
25000	.00269	.00037	.00158	.00012	.00111	.00025
26000	.00336	.00067	.00188	.00030	.00148	.00037
27000	.00382	.00046	.00180	—.00008	.00202	.00054
28000	Broke between 27000 and 28000 lbs.					

REPETITIONS OF **C**, O.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the repeated applications of* 22500 *lbs.* (*or* .9 *of breaking weight*) *per square inch, on a solid cylinder* 30 *in. long and* 1.382 *in. diameter, cut from the exterior of trial cylinder* (**C**), *made from equal parts of* 2d *fusion Greenwood and Bloomfield iron.*

Number of repetitions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1	.00208	–	.00138	–	.00070	–
10	.00223	.00015	.00137	—.00001	.00086	.00016
30	.00233	.00010	.00135	—.00002	.00098	.00012
50	.00243	.00010	.00139	+.00004	.00104	.00006
70	.00250	.00007	.00139	.00000	.00111	.00007
After 15 hrs. rest.						
71	.00247	–	.00139	–	.00108	–
100	.00251	.00004	.00140	.00001	.00111	.00003
150	.00260	.00009	.00140	.00000	.00120	.00009
250	.00271	.00011	.00142	.00002	.00129	.00009
300	.00278	.00007	.00143	.00001	.00135	.00006
350	.00285	.00007	.00143	.00000	.00142	.00007
450	.00311	.00026	.00149	.00006	.00162	.00020
After 15 hrs. rest.						
451	.00309	–	.00148	–	.00161	–
550	.00323	.00014	.00151	.00003	.00172	.00011
650	.00332	.00009	.00149	—.00002	.00183	.00011
Broke at 721st repetition.						
Mean, . .	. . . . .	. . . . .	.00142			

REPETITIONS OF **C**, O. — (Duplicate.)

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the repeated application of* 23500 *lbs. (or .94 of breaking weight) per square inch, on a solid cylinder* 30 *in. long and* 1.382 *in. diameter, cut from the exterior of trial cylinder* (**C**), *made from equal parts of 2d fusion Greenwood and Bloomfield iron.*

Number of repetitions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1	.00128	—	.00133	—	.00085	—
11	.00245	.00027	.00139	.00006	.00106	.00021
30	.00262	.00017	.00140	.00001	.00122	.00016
50	.00272	.00010	.00140	.00000	.00132	.00010
70	.00281	.00009	.00143	.00003	.00138	.00006
100	.00300	.00019	.00150	.00007	.00150	.00012
150	.00327	.00027	.00157	.00007	.00170	.00020
200	.00334	.00007	.00149	—.00008	.00185	.00015
After 20 hrs. rest.						
201	.00334	—	.00150	—	.00184	—
250	.00337	.00003	.00148	—.00002	.00189	.00005
300	.00348	.00011	.00150	+.00002	.00198	.00009
350	.00356	.00008	.00149	—.00001	.00207	.00009
After 15 hrs. rest.						
351	.00355	—	.00151	—	.00204	—
400	.00357	.00002	.00148	—.00003	.00209	.00005
450	.00374	.00017	.00154	+.00006	.00220	.00011
457	Broke at 457th repetition.					
Mean, . .	. . . .	. . . .	.00146			

60

EXTENSION OF **D**, O.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder 30 in. long and 1.382 in. diameter, cut from exterior of trial cylinder* (**D**), *made from Greenwood and Salisbury iron, re-melted.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00003	–	.00003	–	–	–
2000	.00009	.00006	.00009	.00006	–	–
3000	.00016	.00007	.00016	.00007	–	–
4000	.00021	.00005	.00021	.00005	–	–
5000	.00026	.00005	.00025	.00004	.00001	–
6000	.00033	.00007	.00032	.00007	.00001	.00000
7000	.00040	.00007	.00038	.00006	.00002	.00001
8000	.00047	.00007	.00045	.00007	.00002	.00000
9000	.00054	.00007	.00051	.00006	.00003	.00001
10000	.00061	.00007	.00056	.00005	.00005	.00002
11000	.00069	.00008	.00063	.00007	.00006	.00001
12000	.00078	.00009	.00070	.00007	.00008	.00002
13000	.00085	.00007	.00074	.00004	.00011	.00003
14000	.00094	.00009	.00079	.00005	.00015	.00004
15000	.00106	.00012	.00086	.00007	.00020	.00005
16000	.00119	.00013	.00094	.00008	.00025	.00005
17000	.00135	.00016	.00101	.00007	.00034	.00009
18000	.00150	.00015	.00107	.00006	.00043	.00009
19000	.00171	.00021	.00115	.00008	.00056	.00013
20000	.00194	.00023	.00121	.00006	.00073	.00017
21000	.00231	.00037	.00130	.00009	.00101	.00028
22000	.00278	.00047	.00142	.00012	.00136	.00035
23000	.00327	.00049	.00146	.00004	.00181	.00045
24000	.00424	.00097	.00158	.00012	.00266	.00085
25000	Broke between 24000 and 25000 lbs.					

EXTENSION OF **D**, I.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder* 30 *in. long and* 1.382 *in. diameter, cut from near the axis of trial cylinder* (**D**), *made from Greenwood and Salisbury iron, re-melted.*

Weight per square inch of section.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00002	—	.00002	—	—	—
2000	.00008	.00006	.00008	.00006	—	—
3000	.00012	.00004	.00012	.00004	—	—
4000	.00020	.00008	.00020	.00008	—	—
5000	.00029	.00009	.00029	.00009	—	—
6000,	.00037	.00008	.00036	.00007	.00001	—
7000	.00047	.00010	.00045	.00009	.00002	.00001
8000	.00057	.00010	.00053	.00008	.00004	.00002
9000	.00069	.00012	.00062	.00009	.00007	.00003
10000	.00081	.00012	.00070	.00008	.00011	.00004
11000	.00096	.00015	.00080	.00010	.00016	.00005
12000	.00114	.00018	.00091	.00011	.00023	.00007
13000	.00132	.00018	.00100	.00009	.00032	.00009
14000	.00156	.00024	.00115	.00015	.00045	.00013
15000	.00184	.00028	.00122	.00007	.00062	.00017
16000	.00223	.00039	.00136	.00014	.00087	.00025
17000	Broke between 16000 and 17000 lbs.					

REPETITIONS OF **D**, O.

TABLE *showing the extension, restoration and permanent set, per inch in length, caused by the repeated application of* 21600 *lbs. (or .9 of breaking weight) per square inch, on a solid cylinder* 30 *in. long and* 1.382 *in. diameter, cut from the exterior of trial cylinder* (**D**), *made from Greenwood and Salisbury iron, re-melted.*

Number of repetitions.	Extension per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1	.00271	—	.00143	—	.00128	—
10	.00307	.00036	.00148	.00005	.00159	.00031
30	.00337	.00030	.00148	.00000	.00189	.00030
50	.00354	.00017	.00149	.00001	.00205	.00016
70	.00371	.00017	.00150	.00001	.00221	.00016
100	.00402	.00031	.00149	—.00001	.00253	.00032
150	.00427	.00025	.00148	—.00001	.00279	.00026
171	Broke at the 172d repetition.					
Mean, . .	. . . . .	. . . . .	.00148			

COMPRESSION OF **A**, O.

TABLE *showing the compression, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder 10 in. long and 1.382 in. diameter, cut from exterior of trial cylinder (***A***), made of 2d fusion Bloomfield iron.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00003	—	.00003	—	—	—
2000	.00008	.00005	.00008	.00005	—	—
3000	.00013	.00005	.00013	.00005	—	—
4000	.00019	.00006	.00019	.00006	—	—
5000	.00023	.00004	.00023	.00004	—	—
6000	.00029	.00006	.00029	.00006	—	—
7000	.00034	.00005	.00034	.00005	—	—
8000	.00038	.00004	.00038	.00004	—	—
9000	.00044	.00006	.00044	.00006	—	—
10000	.00049	.00005	.00049	.00005	—	—
11000	.00054	.00005	.00054	.00005	—	—
12000	.00059	.00005	.00058	.00004	.00001	—
13000	.00063	.00004	.00061	.00003	.00002	.00001
14000	.00068	.00005.	.00066	.00005	.00002	.00000
15000	.00073	.00005	.00070	.00004	.00003	.00001
16000	.00080	.00007	.00077	.00007	.00003	.00000
17000	.00085	.00005	.00081	.00004	.00004	.00001
18000	.00091	.00006	.00087	.00006	.00004	.00000
19000	.00096	.00005	.00091	.00004	.00005	.00001
20000	.00102	.00006	.00097	.00006	.00005	.00000
21000	.00109	.00007	.00103	.00006	.00006	.00001
22000	.00116	.00007	.00107	.00004	.00009	.00003
23000	.00120	.00004	.00111	.00004	.00009	.00000
24000	.00126	.00006	.00114	.00003	.00012	.00003
25000	.00136	.00010	.00122	.00008	.00014	.00002
26000	.00142	.00006	.00125	.00003	.00017	.00003
27000	.00149	.00007	.00127	.00002	.00022	.00005
28000	.00161	.00012	.00135	.00008	.00026	.00004
29000	.00169	.00008	.00139	.00004	.00030	.00004
30000	.00181	.00012	.00145	.00006	.00036	.00006
31000	.00191	.00010	.00150	.00005	.00041	.00005
32000	.00202	.00011	.00154	.00004	.00048	.00007
33000	.00214	.00012	.00157	.00003	.00057	.00009
34000	.00227	.00013	.00161	.00004	.00066	.00009
35000	.00249	.00022	.00167	.00006	.00082	.00016
36000	.00267	.00018	.00171	.00004	.00096	.00014
37000	.00288	.00021	.00172	.00001	.00116	.00020
38000	.00314	.00026	.00178	.00006	.00136	.00020
39000	.00346	.00032	.00181	.00003	.00165	.00029
40000	.00393	.00047	.00192	.00011	.00201	.00036
41000	.00457	.00064	.00146	—.00056	.00311	.00110

COMPRESSION OF A, T.

TABLE *showing the compression, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder* 10 *in. long and* 1.382 *in. diameter, cut transversely* 13 *inches from lower end of trial cylinder* (A), *made of* 2d *fusion Bloomfield iron.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00012	—	.00012	—	—	—
2000	.00022	.00010	.00022	.00010	—	—
3000	.00032	.00010	.00032	.00010	—	—
4000	.00042	.00010	.00042	.00010	—	—
5000	.00051	.00009	.00051	.00009	—	—
6000	.00055	.00004	.00055	00004	—	—
7000	.00060	.00005	.00060	.00005	—	—
8000	.00068	.00008	.00068	.00008	—	—
9000	.00074	.00006	.00073	.00005	.00001	—
10000	.00080	.00006	.00078	.00005	.00002	.00001
11000	.00086	.00006	.00083	.00005	.00003	.00001
12000	.00093	.00007	.00089	.00006	.00004	.00001
13000	.00102	.00009	.00096	.00007	.00006	.00002
14000	.00108	.00006	.00101	.00005	.00007	.00001
15000	.00114	.00006	.00106	.00005	.00008	.00001
16000	.00121	.00007	.00112	.00006	.00009	.00001
17000	.00127	.00006	.00114	.00002	.00013	.00004
18000	.00135	.00008	.00120	.00006	.00015	.00002
19000	.00142	.00007	.00125	.00005	.00017	.00002
20000	.00151	.00009	.00131	.00006	.00020	.00003
21000	.00159	.00008	.00137	.00006	.00022	.00002
22000	.00163	.00004	.00138	.00001	.00025	.00003
23000	.00172	.00009	.00143	.00005	.00029	.00004
24000	.00181	.00009	.00148	.00005	.00033	.00004
25000	.00191	.00010	.00155	.00007	.00036	.00003
26000	.00200	.00009	.00161	.00006	.00039	.00003
27000	.00208	.00008	.00165	.00004	.00043	.00004
28000	.00217	.00009	.00169	.00004	.00048	.00005
29000	.00227	.00010	.00173	.00004	.00054	.00006
30000	.00237	.00010	.00177	.00004	.00060	.00006
31000	.00249	.00012	.00181	.00004	.00068	.00008
32000	.00263	.00014	.00186	.00005	.00077	.00009
33000	.00276	.00013	.00191	.00005	.00085	.00008
34000	.00294	.00018	.00197	.00006	.00097	.00012
35000	.00309	.00015	.00199	.00002	.00110	.00013
36000	.00330	.00021	.00204	.00005	.00126	.00016
37000	.00351	.00021	.00206	.00002	.00145	.00019
38000	.00378	.00027	.00209	.00003	.00169	.00024
39000	.00408	.00030	.00215	.00006	.00193	.00024
40000	.00441	.00033	.00224	.00009	.00217	.00024

COMPRESSION OF **B**, O.

TABLE *showing the compression, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder* 10 *in. long and* 1.382 *in. diameter, cut from exterior of trial cylinder* (**B**), *made of Greenwood and Salisbury iron.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00016	—	.00016	—	—	—
2000	.00025	.00009	.00025	.00009	—	—
3000	.00032	.00007	.00032	.00007	—	—
4000	.00038	.00006	.00038	.00006	—	—
5000	.00045	.00007	.00044	.00006	.00001	—
6000	.00050	.00005	.00048	.00004	.00002	.00001
7000	.00056	.00006	.00053	.00005	.00003	.00001
8000	.00061	.00005	.00057	.00004	.00004	.00001
9000	.00066	.00005	.00061	.00004	.00005	.00001
10000	.00072	.00006	.00066	.00005	.00006	.00001
11000	.00078	.00006	.00072	.00006	.00006	.00000
12000	.00083	.00005	.00076	.00004	.00007	.00001
13000	.00089	.00006	.00081	.00005	.00008	.00001
14000	.00094	.00005	.00085	.00004	.00009	.00001
15000	.00101	.00007	.00090	.00005	.00011	.00002
16000	.00108	.00007	.00096	.00006	.00012	.00001
17000	.00114	.00006	.00100	.00004	.00014	.00002
18000	.00119	.00005	.00104	.00004	.00015	.00001
19000	.00127	.00008	.00110	.00006	.00017	.00002
20000	.00136	.00009	.00117	.00007	.00019	.00002
21000	.00145	.00009	.00122	.00005	.00023	.00004
22000	.00155	.00010	.00127	.00005	.00028	.00005
23000	.00166	.00011	.00134	.00007	.00032	.00004
24000	.00178	.00012	.00141	.00007	.00037	.00005
25000	.00192	.00014	.00147	.00006	.00045	.00008
26000	.00211	.00019	.00155	.00008	.00056	.00011
27000	.00227	.00016	.00159	.00004	.00068	.00012
28000	.00256	.00029	.00168	.00009	.00088	.00020
29000	.00275	.00019	.00172	.00004	.00103	.00015
30000	.00297	.00022	.00173	.00001	.00124	.00021
31000	.00334	.00037	.00180	.00007	.00154	.00030
32000	.00390	.00056	.00183	.00003	.00207	.00053
33000	.00473	.00083	.00186	.00003	.00287	.00080
34000	.00542	.00069	.00195	.00009	.00347	.00060
35000	.00621	.00079	.00201	.00006	.00420	.00073

COMPRESSION OF **B**, T.

TABLE *showing the compression, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder* 10 *in. long and* 1.382 *in. diameter, cut transversely* 13 *in. from the lower end of trial cylinder* (**B**), *made of Greenwood and Salisbury iron.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00010	—	.00010	—	—	—
2000	.00021	.00011	.00021	.00011	—	—
3000	.00029	.00008	.00029	.00008	—	—
4000	.00034	.00005	.00034	.00005	—	—
5000	.00041	.00007	.00041	.00007	—	—
6000	.00047	.00006	.00046	.00005	.00001	—
7000	.00052	.00005	.00050	.00004	.00002	.00001
8000	.00059	.00007	.00056	.00006	.00003	.00001
9000	.00066	.00007	.00062	.00006	.00004	.00001
10000	.00073	.00007	.00068	.00006	.00005	.00001
11000	.00079	.00006	.00074	.00006	.00005	.00000
12000	.00086	.00007	.00080	.00006	.00006	.00001
13000	.00093	.00007	.00085	.00005	.00008	.00002
14000	.00101	.00008	.00092	.00007	.00009	.00001
15000	.00108	.00007	.00097	.00005	.00011	.00002
16000	.00117	.00009	.00104	.00007	.00013	.00002
17000	.00123	.00006	.00108	.00004	.00015	.00002
18000	.00130	.00007	.00112	.00004	.00018	.00003
19000	.00137	.00007	.00117	.00005	.00020	.00002
20000	.00146	.00009	.00124	.00007	.00022	.00002
21000	.00154	.00008	.00130	.00006	.00024	.00002
22000	.00164	.00010	.00136	.00006	.00028	.00004
23000	.00173	.00009	.00141	.00005	.00032	.00004
24000	.00184	.00011	.00147	.00006	.00037	.00005
25000	.00194	.00010	.00152	.00005	.00042	.00005
26000	.00207	.00013	.00158	.00006	.00049	.00007
27000	.00219	.00012	.00162	.00004	.00057	.00008
28000	.00232	.00013	.00167	.00005	.00065	.00008
29000	.00247	.00015	.00171	.00004	.00076	.00011
30000	.00267	.00020	.00177	.00006	.00090	.00014
31000	.00294	.00027	.00194	.00017	.00100	.00010
32000	.00307	.00013	.00187	—.00007	.00120	.00020
33000	.00330	.00023	.00192	+.00005	.00138	.00018
34000	.00358	.00028	.00195	.00003	.00163	.00025
35000	.00396	.00038	.00204	.00009	.00192	.00029
36000	.00434	.00038	.00214	.00010	.00224	.00032
37000	.00475	.00041	.00214	.00000	.00261	.00037
38000	.00525	.00050	.00217	.00003	.00308	.00047
39000	.00583	.00058	.00225	.00008	.00358	.00050
40000	.00666	.00083	.00227	.00002	.00439	.00081
41000	.00745	.00079	.00228	.00001	.00517	.00078
42000	.00845	.00100	.00228	.00000	.00617	.00100

COMPRESSION OF C, O.

TABLE *showing the compression, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder* 10 *in. long and* 1.382 *in. diameter, cut from exterior of trial cylinder* (C), *made from equal parts of* 2d *fusion Greenwood and Bloomfield iron.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00011	–	.00011	–	–	–
2000	.00021	.00010	.00021	.00010	–	–
3000	.00031	.00010	.00031	.00010	–	–
4000	.00037	.00006	.00036	.00005	.00001	–
5000	.00041	.00004	.00038	.00002	.00003	.00002
6000	.00045	.00004	.00041	.00003	.00004	.00001
7000	.00045	.00000	.00038	—.00003	.00007	.00003
8000	.00049	.00004	.00042	+.00004	.00007	.00000
9000	.00056	.00007	.00049	.00007	.00007	.00000
10000	.00064	.00008	.00056	.00007	.00008	.00001
11000	.00067	.00003	.00059	.00003	.00008	.00000
12000	.00073	.00006	.00065	.00006	.00008	.00000
13000	.00085	.00012	.00076	.00011	.00009	.00001
14000	.00089	.00004	.00078	.00002	.00011	.00002
15000	.00098	.00009	.00086	.00008	.00012	.00001
16000	.00108	.00010	.00094	.00008	.00014	.00002
17000	.00113	.00005	.00099	.00005	.00014	.00000
18000	.00116	.00003	.00101	.00002	.00015	.00001
19000	.00125	.00009	.00109	.00008	.00016	.00001
20000	.00131	.00006	.00114	.00005	.00017	.00001
21000	.00135	.00004	.00115	.00001	.00020	.00003
22000	.00145	.00010	.00120	.00005	.00025	.00005
23000	.00151	.00006	.00124	.00004	.00027	.00002
24000	.00161	.00010	.00134	.00010	.00027	.00000
25000	.00171	.00010	.00138	.00004	.00033	.00006
26000	.00179	.00008	.00141	.00003	.00038	.00005
27000	.00191	.00012	.00150	.00009	.00041	.00003
28000	.00200	.00009	.00152	.00002	.00048	.00007
29000	.00217	.00017	.00156	.00004	.00061	.00013
30000	.00231	.00014	.00157	.00001	.00074	.00013
31000	.00257	.00026	.00168	.00011	.00085	.00015
32000	.00278	.00021	.00172	.00004	.00106	.00017
33000	.00310	.00032	.00177	.00005	.00133	.00027
34000	.00336	.00026	.00181	.00004	.00155	.00022
35000	.00369	.00033	.00186	.00005	.00183	.00028
36000	.00403	.00034	.00187	.00001	.00216	.00033
37000	.00526	.00123	.00199	.00012	.00327	.00111
38000	.00574	.00048	.00205	.00006	.00369	.00042
39000	.00622	.00048	.00213	.00008	.00409	.00040
40000	.00683	.00061	.00213	.00000	.00470	.00061

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COMPRESSION OF C, T.

TABLE *showing the compression, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder* 10 *in. long and* 1.382 *in. diameter, cut transversely* 13 *in. from lower end of trial cylinder* (**C**), *made from equal parts of 2d fusion Greenwood and Bloomfield iron.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00011	–	.00011	–	–	–
2000	.00017	.00006	.00017	.00006	–	–
3000	.00025	.00008	.00025	.00008	–	–
4000	.00030	.00005	.00030	.00005	–	–
5000	.00039	.00009	.00038	.00008	.00001	–
6000	.00039	.00000	.00037	—.00001	.00002	.00001
7000	.00048	.00009	.00044	+.00007	.00004	.00002
8000	.00054	.00006	.00050	.00006	.00004	.00000
9000	.00061	.00007	.00057	.00007	.00004	.00000
10000	.00067	.00006	.00062	.00005	.00005	.00001
11000	.00074	.00007	.00069	.00007	.00005	.00000
12000	.00079	.00005	.00073	.00004	.00006	.00001
13000	.00086	.00007	.00079	.00006	.00007	.00001
14000	.00091	.00005	.00082	.00003	.00009	.00002
15000	.00098	.00007	.00088	.00006	.00010	.00001
16000	.00106	.00008	.00095	.00007	.00011	.00001
17000	.00111	.00005	.00098	.00003	.00013	.00002
18000	.00118	.00007	.00103	.00005	.00015	.00002
19000	.00124	.00006	.00103	.00000	.00021	.00006
20000	.00132	.00008	.00111	.00008	.00021	.00000
21000	.00139	.00007	.00117	.00006	.00022	.00001
22000	.00147	.00008	.00120	.00003	.00027	.00005
23000	.00155	.00008	.00126	.00006	.00029	.00002
24000	.00163	.00008	.00129	.00003	.00034	.00005
25000	.00172	.00009	.00133	.00004	.00039	.00005
26000	.00181	.00009	.00141	.00008	.00040	.00001
27000	.00191	.00010	.00146	.00005	.00045	.00005
28000	.00201	.00010	.00150	.00004	.00051	.00006
29000	.00213	.00012	.00154	.00004	.00059	.00008
30000	.00227	.00014	.00160	.00006	.00067	.00008
31000	.00240	.00013	.00165	.00005	.00075	.00008
32000	.00257	.00017	.00169	.00004	.00088	.00013
33000	.00272	.00015	.00168	—.00001	.00104	.00016
34000	.00294	.00022	.00169	+.00001	.00125	.00021
35000	.00316	.00022	.00176	.00007	.00140	.00015
36000	.00341	.00025	.00190	.00014	.00151	.00011
37000	.00370	.00029	.00193	.00003	.00177	.00026
38000	.00409	.00039	.00202	.00009	.00207	.00030
39000	.00444	.00035	.00201	—.00001	.00243	.00036
40000	.00496	.00052	.00210	+.00009	.00286	.00043
41000	.00554	.00058	.00224	.00014	.00330	.00044
42000	.00602	.00048	.00218	—.00006	.00384	.00054
43000	.00650	.00048	.00231	+.00013	.00419	.00035

COMPRESSION OF **D**, O.

TABLE *showing the compression, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a specimen 10 in. long and 1.382 in. diameter, cut from exterior of trial cylinder* (**D**), *made from Greenwood and Salisbury iron, all re-melted.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00008	—	.00008	—	—	—
2000	.00013	.00005	.00013	.00005	—	—
3000	.00017	.00004	.00017	.00004	—	—
4000	.00022	.00005	.00022	.00005	—	—
5000	.00028	.00006	.00028	.00006	—	—
6000	.00034	.00006	.00033	.00005	.00001	—
7000	.00040	.00006	.00039	.00006	.00001	.00000
8000	.00046	.00006	.00044	.00005	.00002	.00001
9000	.00052	.00006	.00049	.00005	.00003	.00001
10000	.00059	.00007	.00056	.00007	.00003	.00000
11000	.00064	.00005	.00060	.00004	.00004	.00001
12000	.00070	.00006	.00065	.00005	.00005	.00001
13000	.00076	.00006	.00070	.00005	.00006	.00001
14000	.00082	.00006	.00075	.00005	.00007	.00001
15000	.00089	.00007	.00082	.00007	.00007	.00000
16000	.00095	.00006	.00087	.00005	.00008	.00001
17000	.00101	.00006	.00092	.00005	.00009	.00001
18000	.00108	.00007	.00097	.00005	.00011	.00002
19000	.00116	.00008	.00105	.00008	.00011	.00000
20000	.00123	.00007	.00111	.00006	.00012	.00001
21000	.00130	.00007	.00116	.00005	.00014	.00002
22000	.00139	.00009	.00122	.00006	.00017	.00003
23000	.00149	.00010	.00128	.00006	.00021	.00004
24000	.00160	.00011	.00132	.00004	.00028	.00007
25000	.00170	.00010	.00135	.00003	.00035	.00007
26000	.00182	.00012	.00140	.00005	.00042	.00007
27000	.00196	.00014	.00143	.00003	.00053	.00011
28000	.00213	.00017	.00147	.00007	.00066	.00013
29000	.00232	.00019	.00150	.00003	.00082	.00016
30000	.00258	.00026	.00152	.00002	.00106	.00024
31000	.00287	.00029	.00156	.00004	.00131	.00025
32000	.00326	.00039	.00159	.00003	.00167	.00036
33000	.00367	.00041	.00162	.00003	.00205	.00038
34000	.00420	.00053	.00165	.00003	.00255	.00050
35000	.00496	.00076	.00172	.00007	.00324	.00069
36000	.00571	.00075	.00176	.00004	.00395	.00071
37000	.00639	.00068	.00176	.00000	.00463	.00068
38000	.00739	.00100	.00179	.00003	.00560	.00097
39000	.00843	.00104	.00098	—.00081	.00745	.00185
40000	.00918	.00075	.00159	+.00061	.00759	.00014

Uncertain beyond 38000 lbs.

COMPRESSION OF **D**, T.

TABLE *showing the compression, restoration and permanent set, per inch in length, caused by the undermentioned weights, per square inch of section, acting on a solid cylinder* 10 *in. long and* 1.382 *in. diameter, cut transversely* 13 *in. from lower end of trial cylinder* (**D**), *made from Greenwood and Salisbury iron, all re-melted.*

Weight per square inch of section.	Compression per inch in length.	First difference.	Restoration per inch in length.	First difference.	Permanent set per inch in length.	First difference.
1000 lbs.	.00000	—	.00000	—	—	—
2000	.00006	—	.00006	—	—	—
3000	.00016	.00010	.00016	.00010	—	—
4000	.00029	.00013	.00029	.00013	—	—
5000	.00036	.00007	.00036	.00007	—	—
6000	.00047	.00011	.00046	.00010	.00001	—
7000	.00051	.00004	.00050	.00004	.00001	.00000
8000	.00059	.00008	.00057	.00007	· .00002	.00001
9000	.00067	.00008	.00064	.00007	.00003	.00001
10000	.00075	.00008	.00069	.00005	.00006	.00003
11000	.00084	.00009	.00076	.00007	.00008	.00002
12000	.00091	.00007	.00081	.00005	.00010	.00002
13000	.00099	.00008	.00087	.00006	.00012	.00002
14000	.00106	.00007	.00092	.00005	.00014	.00002
15000	.00115	.00009	.00099	.00007	.00016	.00002
16000	.00124	.00009	.00105	.00006	.00019	.00003
17000	.00128	.00004	.00106	.00001	.00022	.00003
18000	.00140	.00012	.00114	.00008	.00026	.00004
19000	.00149	.00009	.00119	.00005	.00030	.00004
20000	.00159	.00010	.00124	.00005	.00035	.00005
21000	.00170	.00011	.00130	.00006	.00040	.00005
22000	.00179	.00009	.00136	.00006	.00043	.00003
23000	.00191	.00012	.00141	.00005	.00050	.00007
24000	.00202	.00011	.00146	.00005	.00056	.00006
25000	.00213	.00011	.00151	.00005	.00062	.00006
26000	.00224	.00011	.00152	.00001	.00072	.00010
27000	.00240	.00016	.00159	.00007	.00081	.00009
28000	.00253	.00013	.00160	.00001	.00093	.00012
29000	.00275	.00022	.00167	.00007	.00108	.00015
30000	.00297	.00022	.00172	.00005	.00125	.00017
31000	.00319	.00022	.00174	.00002	.00145	.00020
32000	.00355	.00036	.00184	.00010	.00171	.00026
33000	.00379	.00024	.00181	—.00003	.00198	.00027
34000	.00412	.00033	.00182	+.00001	.00230	.00032
35000	.00457	.00045	.00187	.00007	.00268	.00038
36000	.00500	.00043	.00196	.00007	.00304	.00036
37000	.00550	.00050	.00200	.00004	.00350	.00046
38000	.00615	.00065	.00199	—.00001	.00416	.00066
39000	.00675	.00060	.00207	+.00008	.00468	.00052
40000	.00750	.00075	.00218	.00011	.00532	.00064

TABLE *comparing extensions of outer specimens from trial cylinders* **A, B, C** *and* **D.**

WEIGHT PER SQUARE INCH OF SECTION.	EXTENSION, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	.00002	.00003	.00004	.00003
2000	.00004	.00008	.00008	.00009
3000	.00013	.00013	.00012	.00016
4000	.00019	.00018	.00018	.00021
5000	.00023	.00024	.00022	.00026
6000	.00027	.00030	.00027	.00033
7000	.00033	.00035	.00032	.00040
8000	.00037	.00042	.00041	.00047
9000	.00043	.00048	.00046	.00054
10000	.00049	.00056	.00052	.00061
11000	.00054	.00065	.00059	.00069
12000	.00060	.00074	.00066	.00078
13000	.00066	.00083	.00075	.00085
14000	.00073	.00093	.00083	.00094
15000	.00080	.00108	.00093	.00106
16000	.00087	.00122	.00102	.00119
17000	.00095	.00140	.00114	.00135
18000	.00103	.00160	.00127	.00150
19000	.00112	.00191	.00141	.00171
20000	.00122	.00235	.00156	.00194
21000	.00133	.00291	.00173	.00231
22000	.00144	–	.00196	.00278
23000	.00159	–	.00221	.00327
24000	.00173	–	.00252	.00424
25000	.00191	–	.00287	–
26000	.00210	–	–	–
27000	.00237	–	–	–
28000	.00267	–	–	–
29000	.00303	–	–	–

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TABLE *comparing restoration from extension of outer specimens from trial cylinders* **A, B, C** *and* **D**.

WEIGHT PER SQUARE INCH OF SECTION.	RESTORATION, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	.00002	.00003	.00004	.00003
2000	.00004	.00008	.00008	.00009
3000	.00013	.00013	.00012	.00016
4000	.00019	.00018	.00018	.00021
5000	.00023	.00024	.00021	.00025
6000	.00027	.00030	.00026	.00032
7000	.00033	.00034	.00030	.00038
8000	.00037	.00041	.00039	.00045
9000	.00042	.00046	.00043	.00051
10000	.00047	.00052	.00048	.00056
11000	.00052	.00060	.00054	.00063
12000	.00057	.00067	.00060	.00070
13000	.00062	.00074	.00067	.00074
14000	.00067	.00080	.00074	.00079
15000	.00073	.00090	.00081	.00086
16000	.00078	.00098	.00086	.00094
17000	.00084	.00106	.00094	.00101
18000	.00089	.00115	.00106	.00107
19000	.00096	.00131	.00110	.00115
20000	.00103	.00140	.00118	.00121
21000	.00110	.00154	.00125	.00130
22000	.00116	–	.00135	.00142
23000	.00123	–	.00144	.00146
24000	.00130	–	.00153	.00158
25000	.00138	–	.00160	–
26000	.00145	–	–	–
27000	.00153	–	–	–
28000	.00163	–	–	–
29000	.00172	–	–	–

TABLE *comparing permanent set from extension of outer specimens from trial cylinders* **A, B, C** *and* **D.**

WEIGHT PER SQUARE INCH OF SECTION.	PERMANENT SET, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	—	—	—	—
2000	—	—	—	—
3000	—	—	—	—
4000	—	—	—	—
5000	—	—	.00001	.00001
6000	—	—	.00001	.00001
7000	—	.00001	.00002	.00002
8000	—	.00001	.00002	.00002
9000	.00001	.00002	.00003	.00003
10000	.00002	.00004	.00004	.00005
11000	.00002	.00005	.00005	.00006
12000	.00003	.00007	.00006	.00008
13000	.00004	.00009	.00008	.00011
14000	.00006	.00013	.00009	.00015
15000	.00007	.00018	.00012	.00020
16000	.00009	.00024	.00016	.00025
17000	.00011	.00034	.00020	.00034
18000	.00014	.00045	.00021	.00043
19000	.00016	.00060	.00031	.00056
20000	.00019	.00095	.00038	.00073
21000	.00023	.00137	.00048	.00101
22000	.00028	—	.00061	.00136
23000	.00036	—	.00077	.00181
24000	.00043	—	.00099	.00266
25000	.00053	—	.00127	—
26000	.00065	—	—	—
27000	.00084	—	—	—
28000	.00104	—	—	—
29000	.00131	—	—	—

TABLE *comparing extension of specimens cut from near the axis of trial cylinders* **A, B, C** *and* **D**.

WEIGHT PER SQUARE INCH OF SECTION.	EXTENSION, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	.00003	.00005	.00004	.00002
2000	.00007	.00010	.00008	.00008
3000	.00011	.00015	.00012	.00012
4000	.00016	.00020	.00018	.00020
5000	.00021	.00024	.00022	.00029
6000	.00026	.00030	.00027	.00037
7000	.00029	.00041	.00033	.00047
8000	.00035	.00052	.00038	.00057
9000	.00039	.00059	.00045	.00069
10000	.00050	.00070	.00051	.00081
11000	.00057	.00081	.00058	.00096
12000	.00064	.00091	.00065	.00114
13000	.00071	.00105	.00073	.00132
14000	.00079	.00119	.00081	.00156
15000	.00087	.00139	.00091	.00184
16000	.00096	.00161	.00099	.00223
17000	.00105	—	.00109	—
18000	.00115	—	.00120	—
19000	.00129	—	.00133	—
20000	.00142	—	.00147	—
21000	.00159	—	.00163	—
22000	.00175	—	.00183	—
23000	.00193	—	.00207	—
24000	.00217	—	.00232	—
25000	.00245	—	.00269	—
26000	.00277	—	.00336	—
27000	.00334	—	.00382	—

TABLE *comparing the restoration from extension of specimens cut from near the axis of trial cylinders* **A, B, C** *and* **D**.

WEIGHT PER SQUARE INCH OF SECTION.	RESTORATION, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	.00003	.00005	.00004	.00002
2000	.00007	.00010	.00008	.00008
3000	.00011	.00015	.00012	.00012
4000	.00016	.00020	.00018	.00020
5000	.00021	.00023	.00022	.00029
6000	.00026	.00029	.00026	.00036
7000	.00029	.00039	.00032	.00045
8000	.00034	.00049	.00036	.00053
9000	.00038	.00055	.00043	.00062
10000	.00047	.00065	.00048	.00070
11000	.00053	.00072	.00054	.00080
12000	.00059	.00078	.00060	.00091
13000	.00065	.00086	.00066	.00100
14000	.00072	.00094	.00072	.00115
15000	.00079	.00104	.00080	.00122
16000	.00085	.00112	.00085	.00136
17000	.00091	—	.00092	—
18000	.00097	—	.00098	—
19000	.00108	—	.00106	—
20000	.00115	—	.00114	—
21000	.00124	—	.00122	—
22000	.00131	—	.00131	—
23000	.00138	—	.00137	—
24000	.00147	—	.00146	—
25000	.00156	—	.00158	—
26000	.00163	—	.00188	—
27000	—	—	.00180	—

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TABLE *comparing the permanent set from extension of specimens cut from near axis of trial cylinders* **A, B, C** *and* **D.**

WEIGHT PER SQUARE INCH OF SECTION.	PERMANENT SET, PER INCH IN LENGTH.			
	A	B	C	D
1000 lbs.	—	—	—	—
2000	—	—	—	—
3000	—	—	—	—
4000	—	—	—	—
5000	—	.00001	—	—
6000	—	.00002	.00001	.00001
7000	—	.00002	.00001	.00002
8000	.00001	.00003	.00002	.00004
9000	.00001	.00004	.00002	.00007
10000	.00003	.00005	.00003	.00011
11000	.00004	.00009	.00004	.00016
12000	.00005	.00013	.00005	.00023
13000	.00006	.00019	.00007	.00032
14000	.00007	.00025	.00009	.00042
15000	.00008	.00035	.00011	.00062
16000	.00011	.00049	.00014	.00087
17000	.00014	—	.00017	—
18000	.00018	—	.00022	—
19000	.00021	—	.00027	—
20000	.00027	—	.00033	—
21000	.00035	—	.00041	—
22000	.00044	—	.00052	—
23000	.00055	—	.00070	—
24000	.00070	—	.00086	—
25000	.00089	—	.00111	—
26000	.00114	—	.00148	—
27000	—	—	.00202	—

TABLE *comparing compression of outer specimens from trial cylinders* **A, B, C** *and* **D.**

WEIGHT PER SQUARE INCH OF SECTION.	COMPRESSION, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	.00003	.00016	.00011	.00008
2000	.00008	.00025	.00021	.00013
3000	.00013	.00032	.00031	.00017
4000	.00019	.00038	.00037	.00022
5000	.00023	.00045	.00041	.00028
6000	.00029	.00050	.00045	.00034
7000	.00034	.00056	.00045	.00040
8000	.00038	.00061	.00049	.00046
9000	.00044	.00066	.00056	.00052
10000	.00049	.00072	.00064	.00059
11000	.00054	.00078	.00067	.00064
12000	.00059	.00083	.00073	.00070
13000	.00063	.00089	.00085	.00076
14000	.00068	.00094	.00089	.00082
15000	.00073	.00101	.00098	.00089
16000	.00080	.00108	.00108	.00095
17000	.00085	.00114	.00113	.00101
18000	.00091	.00119	.00116	.00108
19000	.00096	.00127	.00125	.00116
20000	.00102	.00136	.00131	.00123
21000	.00109	.00145	.00135	.00130
22000	.00116	.00155	.00145	.00139
23000	.00120	.00166	.00151	.00149
24000	.00126	.00178	.00161	.00160
25000	.00136	.00192	.00171	.00170
26000	.00142	.00211	.00179	.00182
27000	.00149	.00227	.00191	.00196
28000	.00161	.00256	.00200	.00213
29000	.00169	.00275	.00217	.00232
30000	.00181	.00297	.00231	.00258
31000	.00191	.00334	.00257	.00287
32000	.00202	.00390	.00278	.00326
33000	.00214	.00473	.00310	.00367
34000	.00227	.00542	.00336	.00420
35000	.00249	.00621	.00369	.00496
36000	.00267	—	.00403	.00571
37000	.00288	—	.00526	.00639
38000	.00314	—	.00574	.00739
39000	.00346	—	.00622	—
40000	.00393	—	.00683	—
41000	.00457	—	—	—

TABLE *comparing restoration from compression of outer specimens from trial cylinders* **A, B, C** *and* **D**.

WEIGHT PER SQUARE INCH OF SECTION.	RESTORATION, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	.00003	.00016	.00011	.00008
2000	.00008	.00025	.00021	.00013
3000	.00013	.00032	.00031	.00017
4000	.00019	.00038	.00036	.00022
5000	.00023	.00044	.00038	.00028
6000	.00029	.00048	.00041	.00033
7000	.00034	.00053	.00038	.00039
8000	.00038	.00057	.00042	.00044
9000	.00044	.00061	.00049	.00049
10000	.00049	.00066	.00056	.00056
11000	.00054	.00072	.00059	.00060
12000	.00058	.00076	.00065	.00065
13000	.00061	.00081	.00076	.00070
14000	.00066	.00085	.00078	.00075
· 15000	.00070	.00090	.00086	.00082
16000	.00077	.00096	.00094	.00087
17000	.00081	.00100	.00099	.00092
18000	.00087	.00104	.00101	.00097
19000	.00091	.00110	.00109	.00105
20000	.00097	.00117	.00114	.00111
21000	.00103	.00122	.00115	.00116
22000	.00107	.00127	.00120	.00122
23000	.00111	.00134	.00124	.00128
24000	.00114	.00141	.00134	.00132
25000	.00122	.00147	.00138	.00135
26000	.00125	.00155	.00141	.00140
27000	.00127	.00159	.00150	.00143
28000	.00135	.00168	.00152	.00147
29000	.00139	.00172	.00156	.00150
30000	.00145	.00173	.00157	.00152
31000	.00150	.00180	.00168	.00156
32000	.00154	.00183	.00172	.00159
33000	.00157	.00186	.00177	.00162
34000	.00161	.00195	.00181	.00165
35000	.00167	.00201	.00186	.00172
36000	.00171	—	.00187	.00176
37000	.00172	‑	.00199	.00176
38000	.00178	‑	.00205	.00179
39000	.00181	‑	.00213	—
40000	.00192	‑	.00213	‑
41000	.00146	‑	—	‑

TABLE *comparing permanent set from compression of outer specimens from trial cylinders* **A, B, C** *and* **D.**

WEIGHT PER SQUARE INCH OF SECTION.	PERMANENT SET, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	—	—	—	—
2000	—	—	—	—
3000	—	—	—	—
4000	—	—	.00001	—
5000	—	.00001	.00003	—
6000	—	.00002	.00004	.00001
7000	—	.00003	.00007	.00001
8000	—	.00004	.00007	.00002
9000	—	.00005	.00007	.00003
10000	—	.00006	.00008	.00003
11000 .	—	.00006	.00008	.00004
12000	.00001	.00007	.00008	.00005
13000	.00002	.00008	.00009	.00006
14000	.00002	.00009	.00011	.00007
15000	.00003	.00011	.00012	.00007
16000	.00003	.00012	.00014	.00008
17000	.00004	.00014	.00014	.00009
18000	.00004	.00015	.00015	.00011
19000	.00005	.00017	.00016	.00011
20000	.00005	.00019	.00017	.00012
21000	.00006	.00023	.00020	.00014
22000	.00009	.00028	.00025	.00017
23000	.00009	.00032	.00027	.00021
24000	.00012	.00037	.00027	.00028
25000	.00014	.00045	.00033	.00035
26000	.00017	.00056	.00038	.00042
27000	.00022	.00068	.00041	.00053
28000	.00026	.00088	.00048	.00066
29000	.00030	.00103	.00061	.00082
30000	.00036	.00124	.00074	.00106
31000	.00046	.00154	.00089	.00131
32000	.00048	.00207	.00106	.00167
33000	.00057	.00287	.00133	.00205
34000	.00066	.00347	.00155	.00255
35000	.00082	.00420	.00183	.00324
36000	.00096	—	.00216	.00395
37000	.00116	—	.00327	.00463
38000	.00136	—	.00369	.00560
39000	.00165	—	.00409	—
40000	.00201	—	.00470	—
41000	.00311	—	—	—

TABLE *comparing compression of specimens cut transversely* 13 *in. from lower ends of trial cylinders* **A, B, C** *and* **D.**

WEIGHT PER SQUARE INCH OF SECTION.	COMPRESSION, PER INCH IN LENGTH.			
	A	**B**	**C**	**D**
1000 lbs.	.00012	.00010	.00011	.00000
2000	.00022	.00021	.00017	.00006
3000	.00032	.00029	.00025	.00016
4000	.00042	.00034	.00030	.00029
5000	.00051	.00041	.00039	.00036
6000	.00053	.00047	.00039	.00047
7000	.00060	.00052	.00048	.00051
8000	.00068	.00059	.00054	.00059
9000	.00074	.00066	.00061	.00067
10000	.00080	.00073	.00067	.00075
11000	.00086	.00079	.00074	.00084
12000	.00093	.00086	.00079	.00091
13000	.00102	.00093	.00086	.00099
14000	.00108	.00101	.00091	.00106
15000	.00114	.00108	.00098	.00115
16000	.00121	.00117	.00106	.00124
17000	.00127	.00123	.00111	.00128
18000	.00135	.00130	.00118	.00140
19000	.00142	.00137	.00124	.00149
20000	.00151	.00146	.00132	.00159
21000	.00159	.00154	.00139	.00170
22000	.00163	.00164	.00147	.00179
23000	.00172	.00173	.00155	.00191
24000	.00181	.00184	.00163	.00202
25000	.00191	.00194	.00172	.00213
26000	.00200	.00207	.00181	.00224
27000	.00208	.00219	.00191	.00240
28000	.00217	.00232	.00201	.00253
29000	.00227	.00247	.00213	.00275
30000	.00237	.00267	.00227	.00297
31000	.00249	.00294	.00240	.00319
32000	.00263	.00307	.00257	.00355
33000	.00276	.00330	.00272	.00379
34000	.00294	.00358	.00294	.00412
35000	.00309	.00396	.00316	.00457
36000	.00330	.00434	.00341	.00500
37000	.00351	.00475	.00370	.00550
38000	.00378	.00525	.00409	.00615
39000	.00408	.00583	.00444	.00675
40000	.00441	.00666	.00496	.00750
41000	–	.00745	.00554	–
42000	–	.00845	.00602	–
43000	–	–	.00650	–

TABLE *comparing restoration from compression of specimens cut transversely* 13
in. from lower ends of trial cylinders **A, B, C** *and* **D.**

WEIGHT PER SQUARE INCH OF SECTION.	RESTORATION, PER INCH IN LENGTH.			
	A	B	C	D
1000 lbs.	.00012	.00010	.00011	.00000
2000	.00022	.00021	.00017	.00006
3000	.00032	.00029	.00025	.00016
4000	.00042	.00034	.00030	.00029
5000	.00051	.00041	.00038	.00036
6000	.00055	.00046	.00037	.00046
7000	.00060	.00050	.00044	.00050
8000	.00068	.00056	.00050	.00057
9000	.00073	.00062	.00057	.00064
10000	.00078	.00068	.00062	.00069
11000	.00083	.00074	.00069	.00076
12000	.00089	.00080	.00073	.00081
13000	.00096	.00085	.00079	.00087
14000	.00101	.00092	.00082	.00092
15000	.00106	.00097	.00088	.00099
16000	.00112	.00104	.00095	.00105
17000	.00114	.00108	.00098	.00106
18000	.00120	.00112	.00103	.00114
19000	.00125	.00117	.00103	.00119
20000	.00131	.00124	.00111	.00124
21000	.00137	.00130	.00117	.00130
22000	.00138	.00136	.00120	.00136
23000	.00143	.00141	.00126	.00141
24000	.00148	.00147	.00129	.00146
25000	.00155	.00152	.00133	.00151
26000	.00161	.00158	.00141	.00152
27000	.00165	.00162	.00146	.00159
28000	.00169	.00167	.00150	.00160
29000	.00173	.00171	.00154	.00167
30000	.00177	.00177	.00160	.00172
31000	.00181	.00194	.00165	.00174
32000	.00186	.00187	.00169	.00184
33000	.00191	.00192	.00168	.00181
34000	.00197	.00195	.00169	.00182
35000	.00199	.00204	.00176	.00189
36000	.00204	.00214	.00190	.00196
37000	.00206	.00214	.00193	.00200
38000	.00209	.00217	.00202	.00199
39000	.00215	.00225	.00201	.00207
40000	.00224	.00227	.00210	.00218
41000	–	.00228	.00224	–
42000	–	.00228	.00218	–
43000	–	–	.00231	–

TABLE *comparing permanent set from compression of specimens cut transversely 13 in. from lower ends of trial cylinders* **A, B, C** *and* **D.**

WEIGHT PER SQUARE INCH OF SECTION.	PERMANENT SET, PER INCH IN LENGTH.			
	A	B	C	D
1000 lbs.	–	–	–	–
2000	–	–	–	–
3000	–	–	–	–
4000	–	–	–	–
5000	–	–	.00001	–
6000	–	.00001	.00002	.00001
7000	–	.00002	.00004	.00001
8000	–	.00003	.00004	.00002
9000	.00001	.00004	.00004	.00003
10000	.00002	.00005	.00005	.00006
11000	.00003	.00005	.00005	.00008
12000	.00004	.00006	.00006	.00010
13000	.00006	.00008	.00007	.00012
14000	.00007	.00009	.00009	.00014
15000	.00008	.00011	.00010	.00016
16000	.00009	.00013	.00011	.00019
17000	.00013	.00015	.00013	.00022
18000	.00015	.00018	.00015	.00026
19000	.00017	.00020	.00021	.00030
20000	.00020	.00022	.00021	.00035
21000	.00022	.00024	.00022	.00040
22000	.00025	.00028	.00027	.00043
23000	.00029	.00032	.00029	.00050
24000	.00033	.00037	.00034	.00056
25000	.00036	.00042	.00039	.00062
26000	.00039	.00049	.00040	.00072
27000	.00043	.00057	.00045	.00081
28000	.00048	.00065	.00051	.00093
29000	.00054	.00076	.00059	.00108
30000	.00060	.00090	.00067	.00125
31000	.00068	.00100	.00075	.00145
32000	.00077	.00120	.00088	.00171
33000	.00085	.00138	.00104	.00198
34000	.00097	.00163	.00125	.00230
35000	.00110	.00192	.00140	.00268
36000	.00126	.00224	.00151	.00304
37000	.00145	.00261	.00177	.00350
38000	.00169	.00308	.00207	.00416
39000	.00193	.00358	.00243	.00468
40000	.00217	.00439	.00286	.00532
41000	–	.00517	.00330	–
42000	–	.00617	.00384	–
43000	–	–	.00419	–

TABLE *showing the general properties of the Iron in Trial Cylinders* **A**, **B**, **C** *and* **D**.

PROPERTIES TESTED.	A O.	A L.	B O.	B L.	C O.	C L.	D O.	D L.
Density,	7.2665	7.2743	7.1776	7.2020	7.2546	7.2804	7.2208	7.2296
Tenacity,	30117	31681	23617	24260	28220	27147	25627	24767
Ultimate extension,	.00303	.00334	.00291	.00161	.00287	.00382	.00424	.00223
Ultimate restoration from extension,	.00172	.00163	.00154	.00112	.00164	.00180	.00158	.00136
Ultimate set from extension,	.00131	.00114	.00137	.00049	.00127	.00202	.00266	.00087
Compression per inch, at 35000 lbs.,	.00249	.00309	.00621	.00396	.00369	.00316	.00496	.00457
Restoration from compression, at 35000 lbs.,	.00167	.00199	.00201	.00204	.00186	.00176	.00172	.00189
Set from compression, at 35000 lbs.,	.00082	.00110	.00420	.00192	.00183	.00140	.00324	.00268
Ultimate resistance to crushing force,	122150	118670	98484	89325	109290	103666	103210	100168
Transverse resistance $S = \dfrac{L W}{4 b d^2}$,	9372	7881	8301	6096	8709	6974	5450	5904

NOTE.—Specimens for ultimate resistance to crushing force were .8 in. in diameter, and 2 in. long.

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Repetition of Strain.

A, o., broke at the   2301st repetition of 22000 lbs. per square inch.

A, o., duplicate, broke at the 282d   "   26000 "   "   "

B, o., broke at the   252d   "   20000 "   "   "

B, o., duplicate, broke at the 150th   "   20000 "   "   "

C, o., broke at the   651st   "   22500 "   "   "

C, o., duplicate, broke at the 457th   "   23500 "   "   "

D, o., broke at the   172d   "   21600 "   "   "

Water Test, and Tangential Resistance.

	A	**B**	**C**	**D**
	lbs.	lbs.	lbs.	lbs.
Water forced through the pores, at (per square inch), .	25464	15276	21845	19099
Tangential resistance, or bursting force, per square inch,	42908	30176	43162	37815

The cylinders for water test and tangential resistance were 5 inches long, 1 inch bore, open at both ends, and 1 inch thick; they were burst, by pressure, upon a composition of three parts of bees-wax to one of tallow.

The following ratios serve to compare the general properties of one variety of iron with those of another :—

$$\frac{\text{Mean tenacity} \times \text{mean extensibility} \times \text{mean restoration}}{\text{Compression at 35000 lbs.} \times \text{mean set}} = 38762, \text{ for cylinder } A.$$

$$\frac{\text{Mean tenacity} \times \text{mean extensibility} \times \text{mean restoration}}{\text{Compression at 35000 lbs.} \times \text{mean set}} = 8764, \text{ for cylinder } B.$$

$$\frac{\text{Mean tenacity} \times \text{mean extensibility} \times \text{mean restoration}}{\text{Compression at 35000 lbs.} \times \text{mean set}} = 29205, \text{ for cylinder } C.$$

$$\frac{\text{Mean tenacity} \times \text{mean extensibility} \times \text{mean restoration}}{\text{Compression at 35000 lbs.} \times \text{mean set}} = 11809, \text{ for cylinder } D.$$

Cylinder (**A**) was the only one of the four found to be entirely sound in all its parts, all the others being more or less defective in their interior parts.

The curves on Plates 10 to 17 are constructed from the foregoing tables, and give an ocular exhibition of the properties of the iron tested, and an ocular comparison of the properties of the different irons.

PLATE X

Curves comparing extensibility, compressibility, and set of outer
Specimens from Cylinder A.
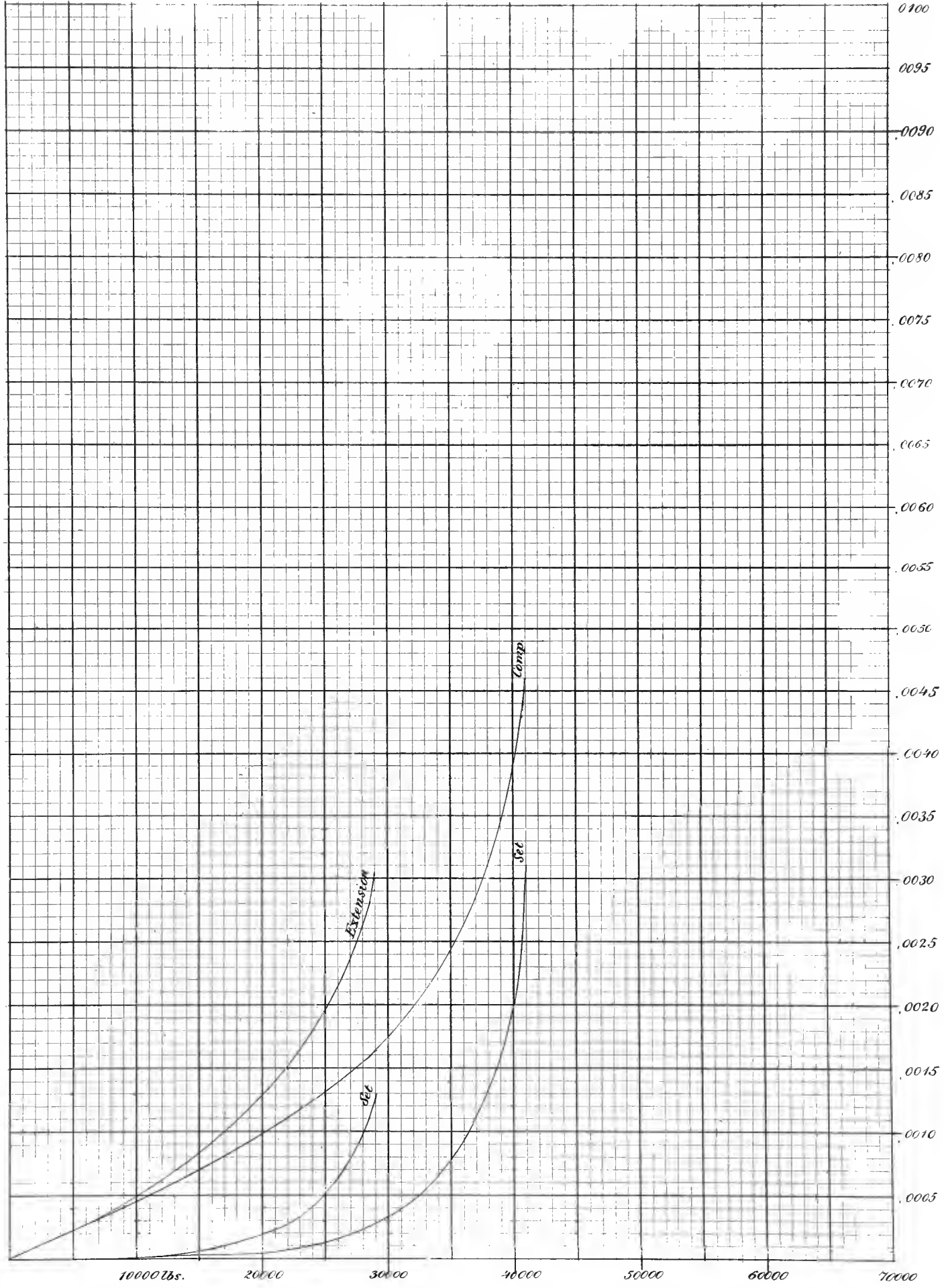
PLATE XI

Curves comparing extensibility, compressibility, and set
of outer Specimens from Cylinder B.
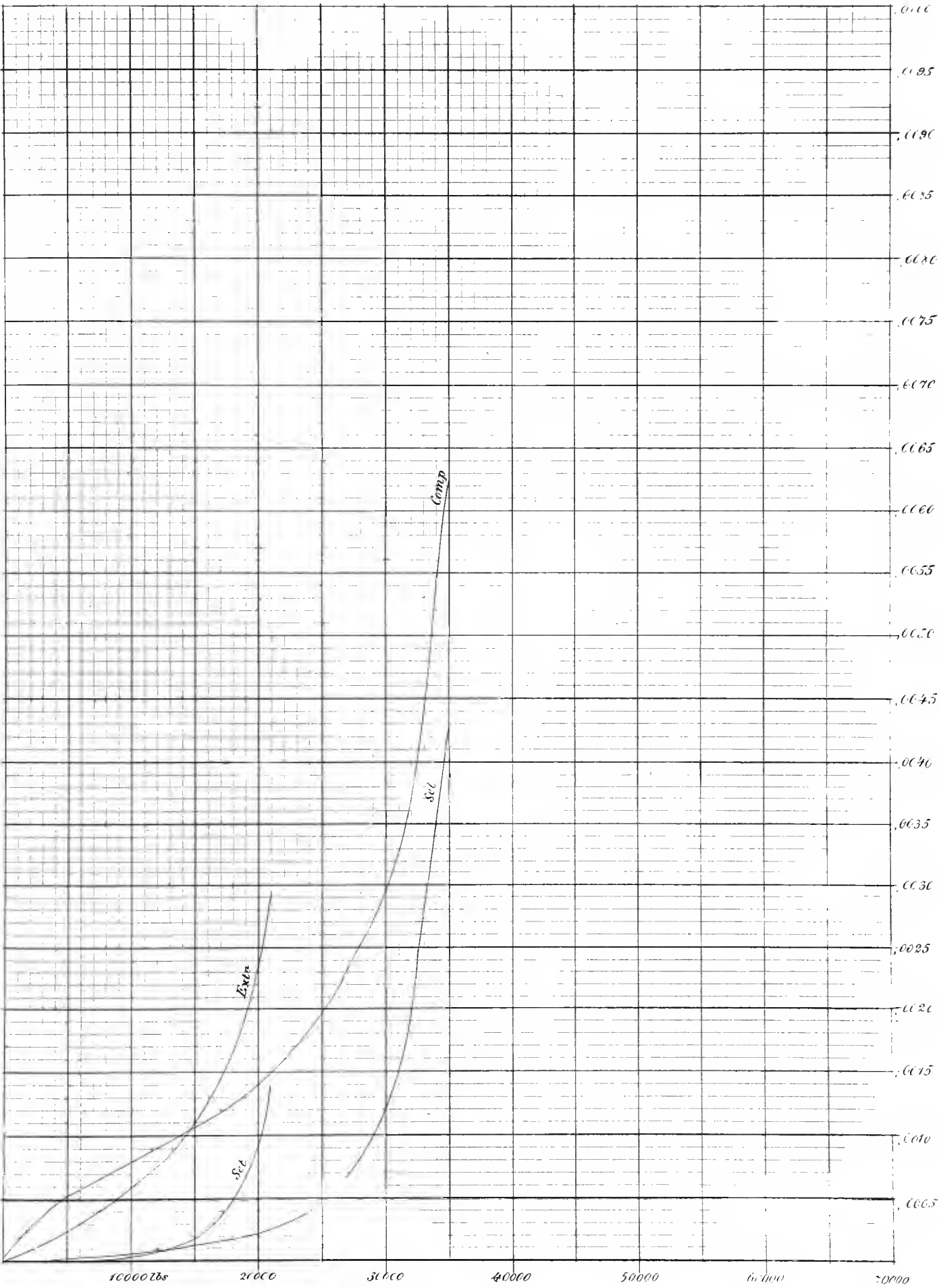
PLATE XII.

Curves comparing extensibility, compressibility, and set of outer
Specimens from Cylinder C.

PLATE XIII.
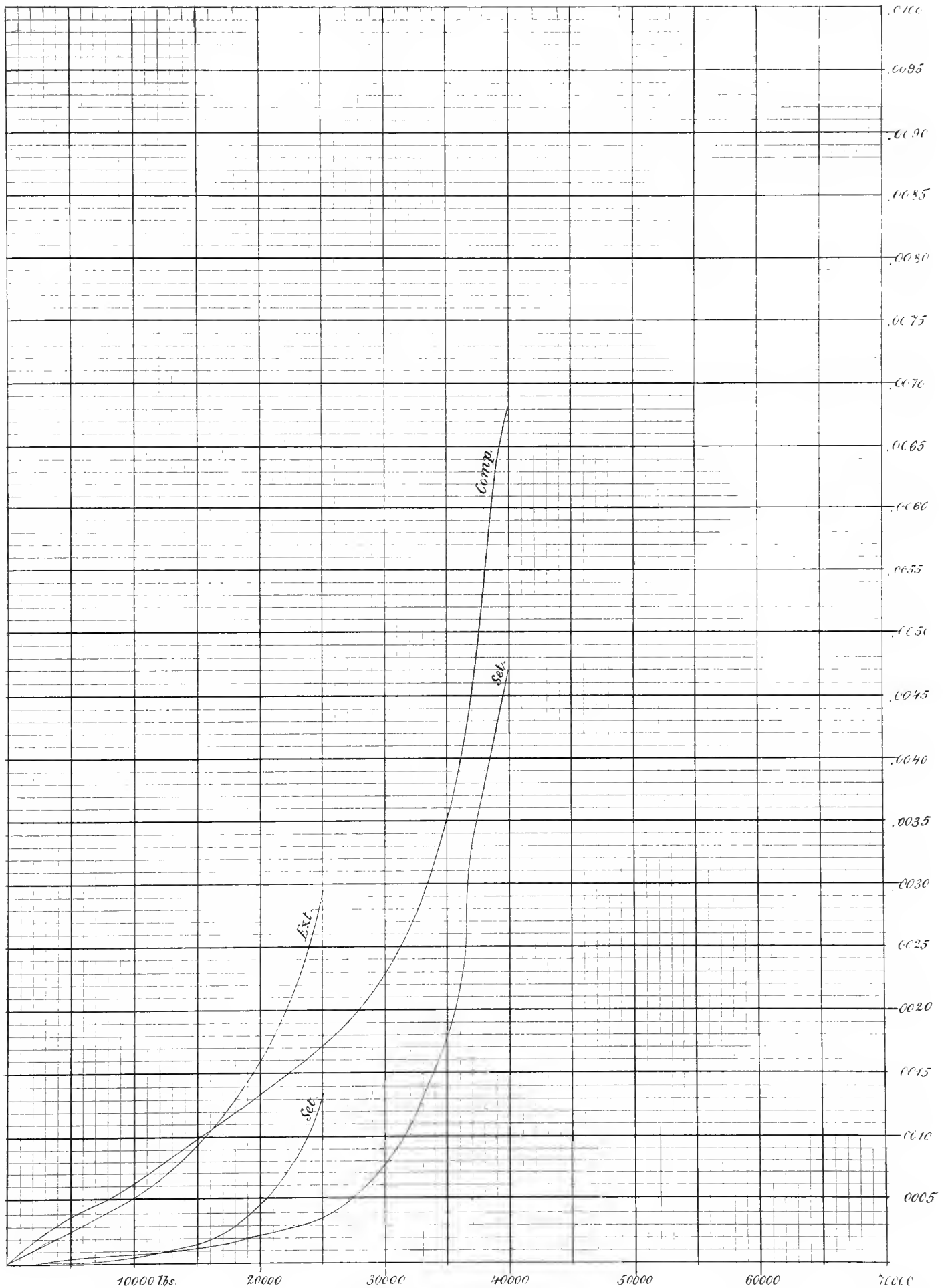
Curves comparing extensibility, compressibility and set of outer
Specimens from Cylinder D.

PLATE XIV.

Comparing extensibility and set of outer Specimens from
Cylinders A, B, C, and D.

PLATE XV
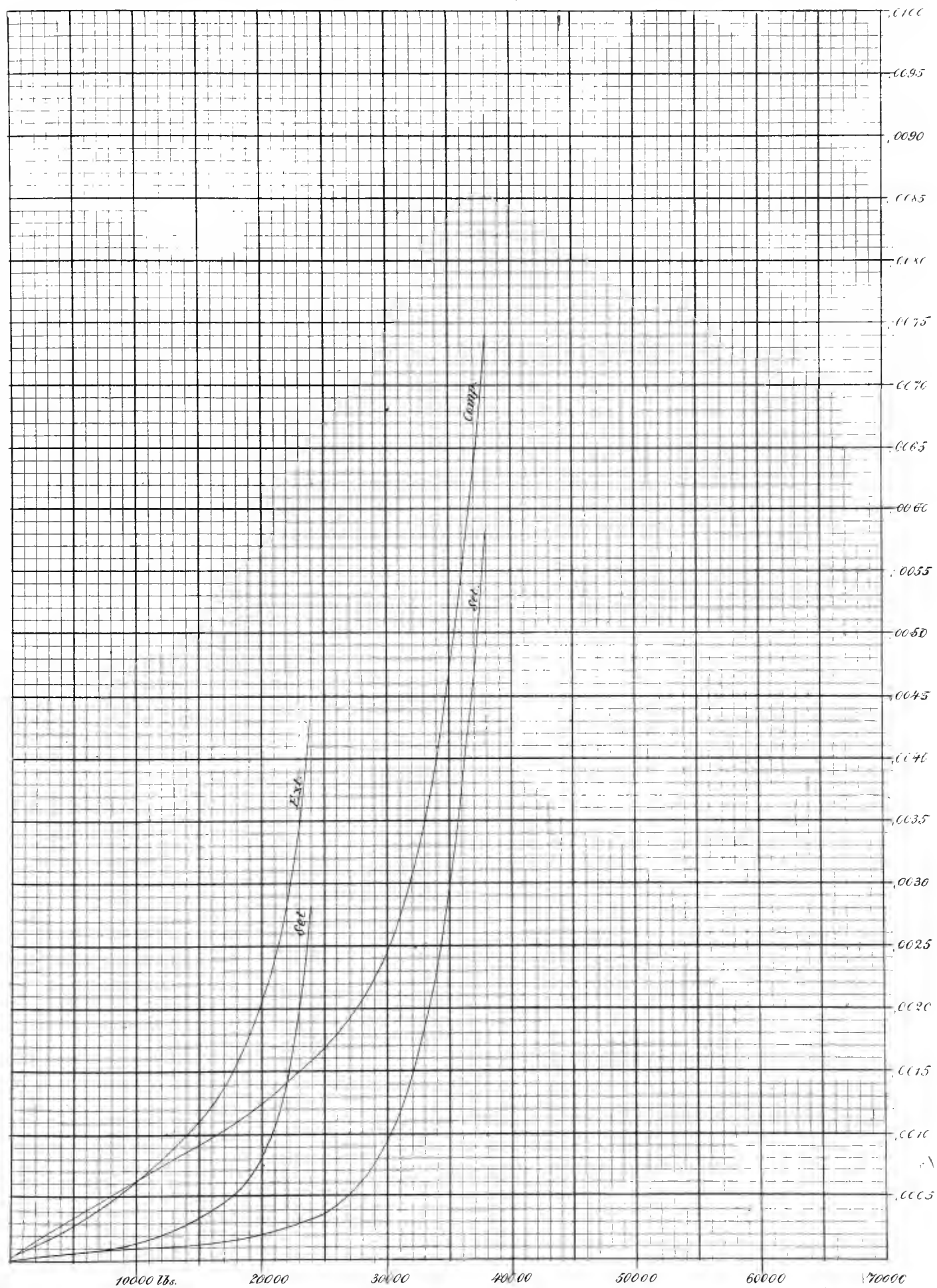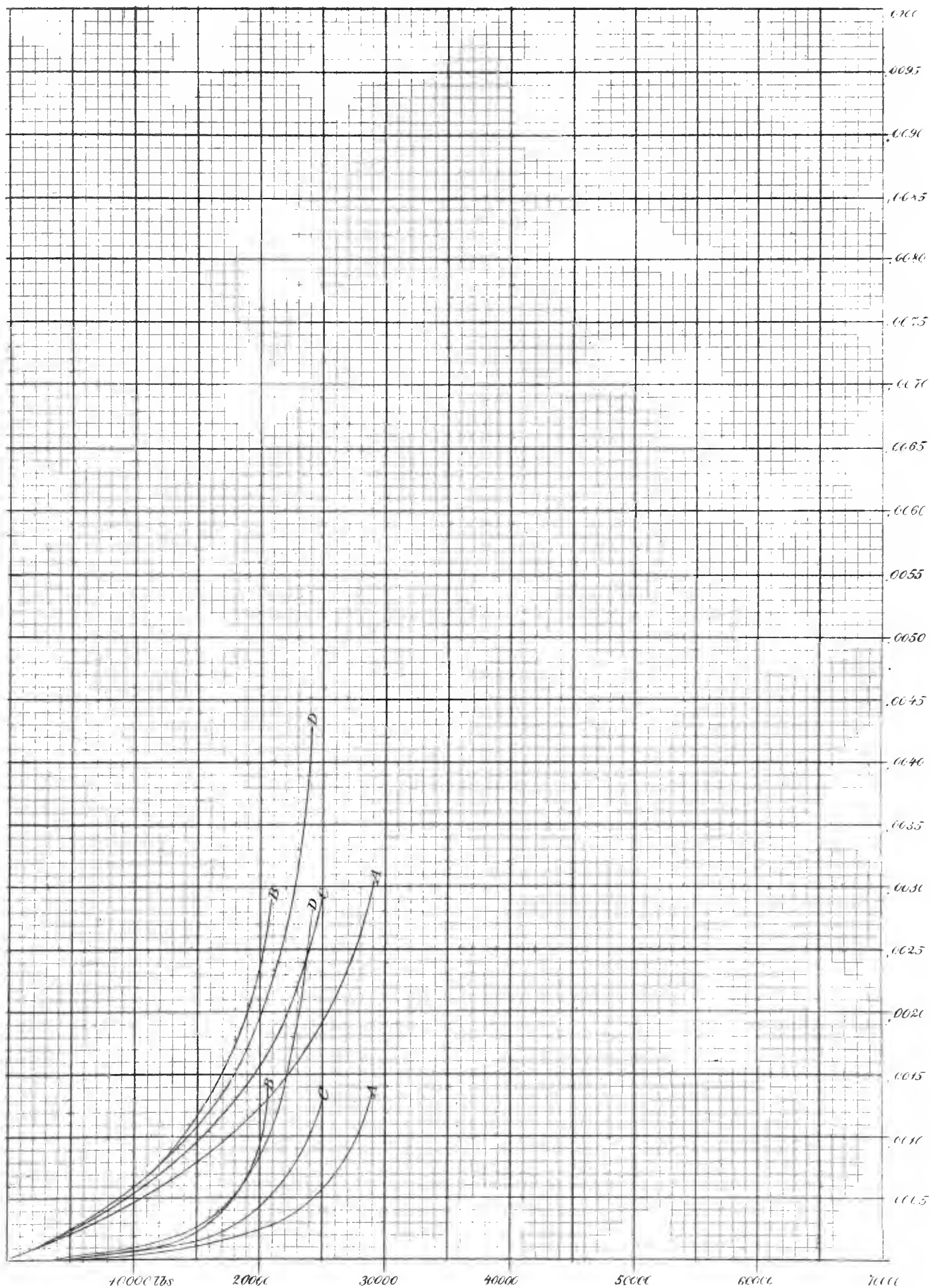
Comparing compressibility and set of transverse Specimens
from Cylinders A, B, C, and D.
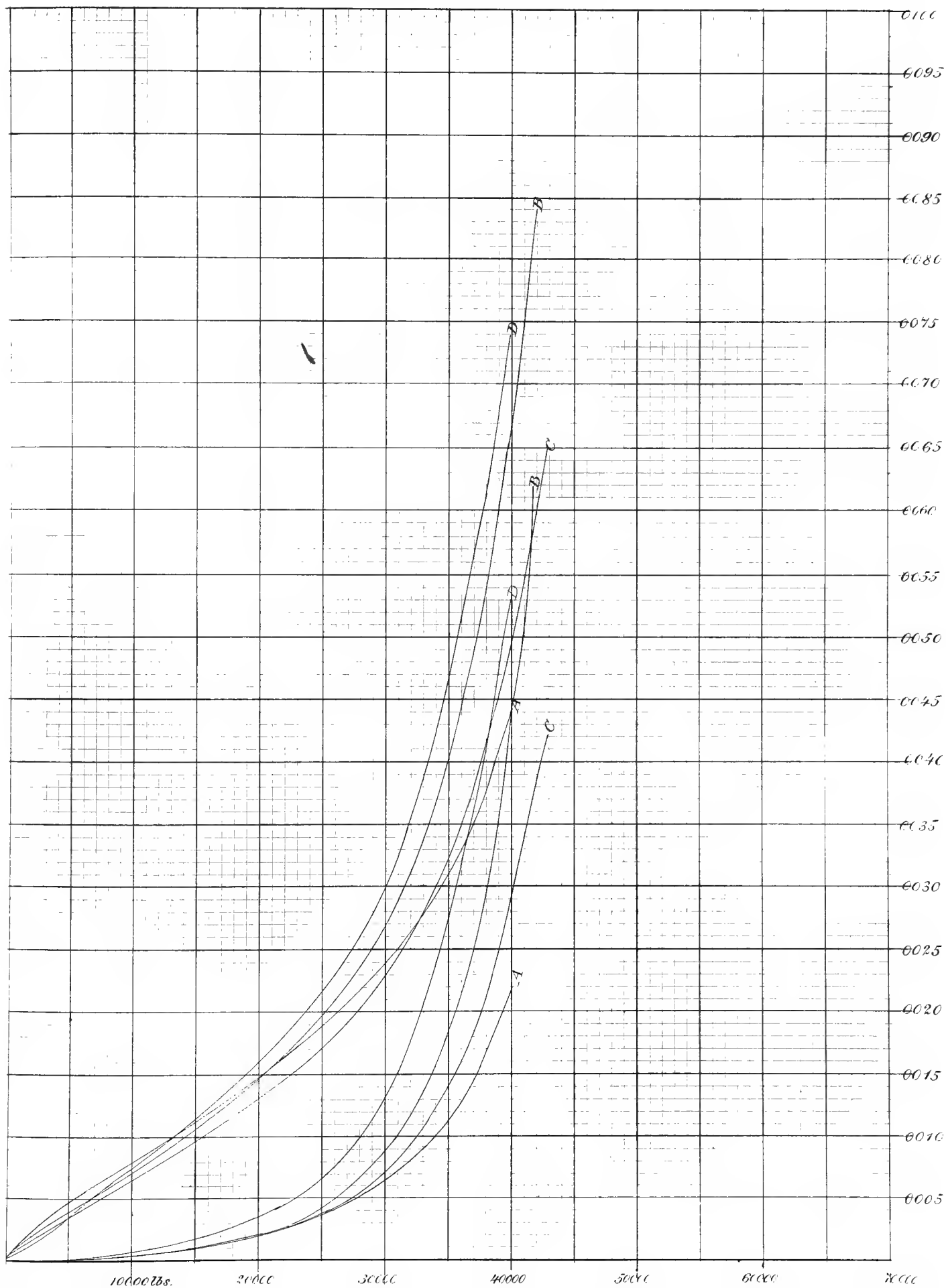
PLATE XVI

Comparing compressibility and set of outer specimens from
trial Cylinders A. B. C and D.

PLATE XVII.
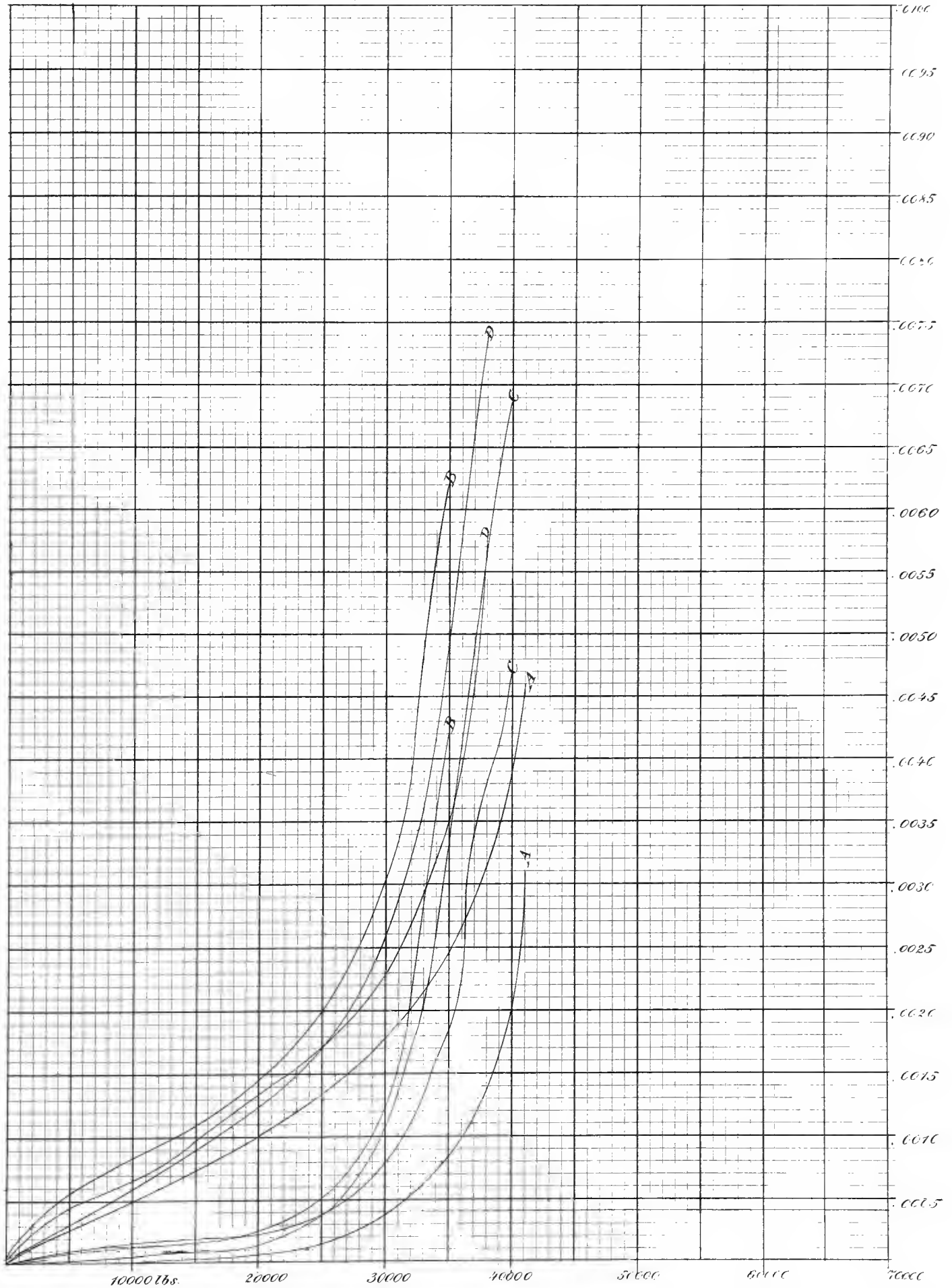
Comparing extensibility and set of specimens from near axes of
Cylinders A,B, C and D.
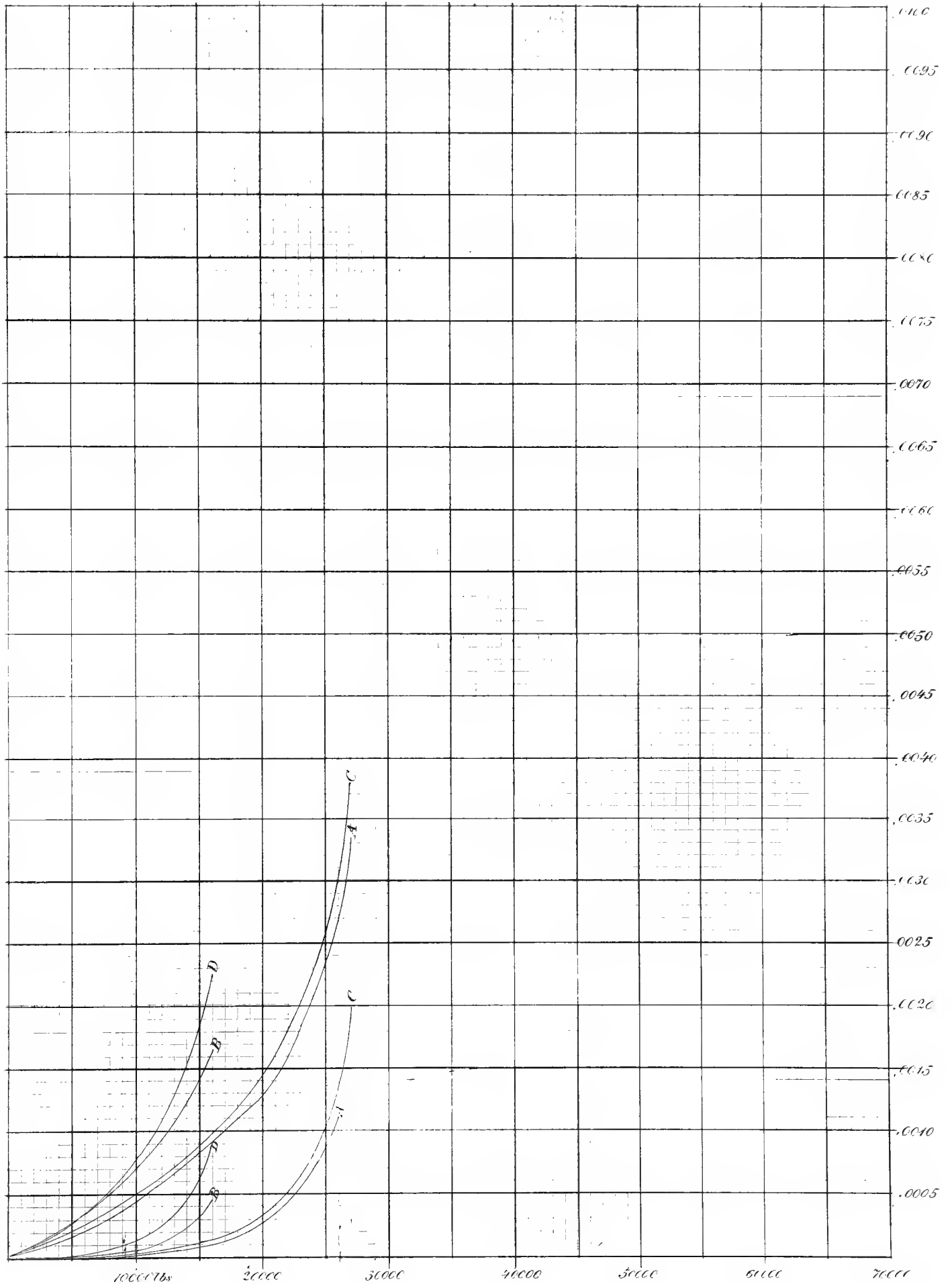
FABRICATION OF 15-INCH GUN.

The foregoing experiments having shown that from our present knowledge of the requisite properties of gun iron, re-melted Bloomfield iron would be more likely to give a durable gun of this size than any other tested, it was determined that the gun should be made of this iron.

Accordingly, on the 22d of December, 1859, the furnaces Nos. 1, 2, and 3, were charged with this quality of iron.

Furnace No. 1 received	16046 lbs.
" No. 2 "	32055 "
" No. 3 "	28069 "
Total charge, ...	76170 lbs.

The gun mould was placed in the pit on the same day, the pit having been previously well dried by fire, and the grate bars arranged in order for heating the mould, so as to prevent the gun from cooling from the exterior.

Casting.

The furnaces were lighted on the 23d; No. 2 at 5h. 30′ A. M., and Nos. 1 and 3 at 6h. A. M., and the iron in all the furnaces was melted at 10h. A. M.

Furnace No. 2 was tapped at 10h. 51′; No. 1 at 10h. 57′, and No. 3 at 11h. 2′; and the whole time of running was 21′.

Furnace No. 1 was tapped a little before No. 2 had run out, and No. 3 a little before No. 1 had run out; so that the iron flowed from but one furnace at the same time.

The iron was conducted from the furnaces, in runners, to a pool near the gun mould, from which it ran in two runners to the gun mould, which it entered through side gates cut into the walls of the mould, the main gates having branch gates inclined upward, at intervals of 12 inches from bottom to top of the mould. The iron entered in directions towards the axis of the mould, and not so as to produce a swirl.

The first metal that entered the mould had a considerable distance to run, along a comparatively cold runner, and was so cold, by the time it reached the gun mould, as to require assistance to make it flow.

This was very soon corrected, as the runners became heated by the passing metal, after which the casting proceeded, with perfect regularity, to completion.

It was intended that the coldest metal should enter first, and remain in the breech of the gun ; the hottest metal, that in No. 3 furnace, which was close to the gun mould, was reserved for the chase and sprue head, in order that it might "feed" as long as possible.

The "swirl" was not used ; and it is believed never should be in casting cannon, for the reason that it forces the scoria and lightest metal in around the bore, where the heaviest and best metal is required.

Cooling.

Water circulated through the core barrel at the rate of about 40 gallons per minute, entering at 36°, and leaving at 60° Fahrenheit.

Cooling Table.

Hours after Casting.	Water entered at	Left at	Change of Temperature.
1h.	36°	58°	22° = 7° for 3 hrs. flow.
4	36	56	20
7	36	54	18
10	36	52	16
13	36	51	15
16	36	49	13
18	36	48	12
21	36	47	11
24	36	47	11

The core barrel was then removed, and water circulated through the cavity thus left, at the rate of 43 gallons per minute.

24h. 30m.	36°	86°	50°
25	36	82	46
28	36	76	40
31	36	67	31
34	36	62	26
37	36	59	23
40	36	56	20
43	36	52	16
46	36	50	14
49	36	49	13
52	36	48	12
55	36	47	11
58	36	47	11
61	36	47	11
64	36	47	11
67	36	46	10
70	36	45	9
73	36	44	8
76	36	43	7
79	36	43	7
82	36	43	7
85	36	43	7
88	36	43	7
91	36	42	6
94	36	42	6
97	36	42	6
100	36	42	6
103	36	42	6
106	36.	41	5
109	36	40	4
112	36	39	3
115	36	38	2
118	36	38	2
121	36	38	2
124	36	38	2
127	36	38	2
130	36	37	1
142	36	37	1
145	36	36° 5′	0° 5′
168	36	36° 5′	0° 5′
			690°

The water was then stopped, and the flask and mould removed from the chase of the gun; just one week being occupied in cooling. The gun and mould, as far as stripped, were perfectly cold, and the temperature of the water that remained in the bore of the gun only reached 50° at three hours after the water had ceased to flow, and only 60° at twenty-four hours after; this gun having been cooled in *less time* than is required for the proper cooling of an *8-inch solid cast gun.*

Temperature of Pitt.

Fire was lighted in the pit at 6 P. M. on the 23d (day of casting), and kept up till 12 M. on the 26th; after which time no more fuel was added, and the fire gradually burned out.

Up to this time, the temperature of the pit had been such that the iron cover would char, and ignite dry wood in 10′ to 15′; the lower part of the flask being at a dull red heat.

The pit cover was removed at 6 P. M. on the 28th, at which time the temperature of the pit was 115°.

The pattern for this gun was 50 inches in diameter at the largest part, and 38 inches at the muzzle; and there were about 9 inches thickness of mould around the gun below the trunnions, and about 8 inches above that point. The flask was of circular cross section in all its parts.

Rate, Extent, and Effects of Internal Cooling.

Previous to the removal of the core barrel, water circulated at the rate of 40 gallons per minute.

Taking the weight of one gallon = 8.33 lbs., and we have for the weight of water that passed through the gun per hour = 19992 lbs., and for that which passed in three hours = 59976 lbs.

And since the temperature was (with one or two exceptions) taken at intervals of three hours, if we suppose the temperature to remain constant for intervals of three hours, and equal to that at the ends of these intervals, then 59976 lbs., multiplied by the sum of the temperatures, up to any given time after casting, will give something less than the number of pounds of water which the heat carried off by it would raise one degree in temperature.

This number, divided by the number of pounds of water which the heat given out by one pound of melted iron would raise one degree, in cooling

down to 105°, will give the number of pounds of iron which the heat carried off by the water would raise from 105° to the casting temperature.

Major Wade found (Reports of Experiments on Metals for Cannon, p. 303) that one pound of iron, in cooling from the common casting temperature down to 105°, gave out sufficient heat to raise 455 lbs. of water one degree.

Calculations based upon the foregoing hypothesis and data show that, up to the time the core barrel was removed, the circulating water had carried off sufficient heat to cool 12879 lbs. of iron from the temperature of casting down to 105°; and that, at fifty-five hours after casting, when the change of temperature became constant, there had been sufficient heat abstracted by the water to cool 55673 lbs. from the casting temperature to 105°; and, consequently, since the total weight of the casting was 76170 lbs., that over two-thirds of all the heat in the gun at the time of casting had, at fifty-five hours after, been carried off from the interior of the gun. When the change of temperature in the circulating water becomes constant, it indicates that the gun is receiving as much heat from the exterior as the water is carrying off from the interior.

There must, consequently (at this time), be a regular decrease in the temperature of the metal from the exterior to the interior, and a greater amount of contraction yet to take place in the exterior than in the interior portions of the gun.

In undergoing this greater amount of contraction, the exterior portions of the gun must, when cold, hug or bind tightly upon the interior; which, in addition to placing the strongest and most compact metal around the bore of the gun, is the principal object of internal cooling.

Mechanical Tests.

Specimens taken from rings cut from the chase of the gun gave, as tested by me, —

For inner ring,	Density = 7.204,	Tenacity = 34.187.
For outer ring,	Density = 7.216,	Tenacity = 33.758.
As tested by founders,	Density = 7.234,	Tenacity = 36.163.

Specimens from the trial cylinder, made of the same composition of iron (re-melted Bloomfield), gave, —

For inner specimen,   D. = 7.274,   and S. = 31.681.

For outer specimen,   D. = 7.266,   and S. = 30.117.

From which it appears, that while the density has been diminished, the tenacity has been increased, by casting in the larger mass.

The metal in this gun is fine grained, presenting an uniform and rather finely mottled appearance; the fractured surface is rough, jagged, and sharp to the touch, with strongly adhering fragments, which are indications of toughness.

The elasticity, extensibility, and compressibility of the iron in the gun have not been determined; but, as far as any judgment can be formed from the tests to which it has been subjected, and from the fracture and appearance of the metal, it is superior in quality to what was expected in so large a casting.

Of the Rate of Application of Force.

The remarks following this point (*) in the discussion of this subject, at page 42, Report of 1857, require modification.

The excess of strain due to the rate of application of any force, above that due to its statical equilibrium, is caused by the momentum or living force developed in both the straining and resisting bodies, up to the time when they attain their position of statical equilibrium, or by the momentum with which they arrive at that position.

To illustrate : suppose the sum of the masses of the resisting body $(a\,b)$,

and of the weight (p), to become infinitely small, as compared with that assigned them in the discussion above referred to ; and the force of gravity to be so increased as to cause their weight to remain constant, and the resisting power of $(a\,b)$ to remain the same.
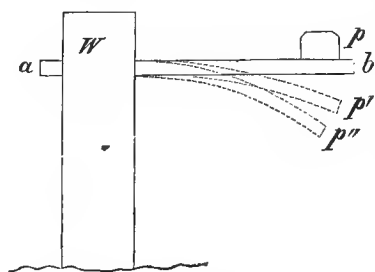
These hypotheses would not change the position of statical equilibrium, and the moving and resisting bodies would reach that position with the same velocity as before ; but their mass being, by hypothesis, infinitely small, their momentum at that position would also be infinitely small, as compared with its value under the former hypothesis, and they would consequently be carried, by that momentum, only an infinitely small

distance beyond the position of statical equilibrium. The ultimate strain would, consequently, under this hypothesis, be independent of the rate of application of the straining force.

The statical pressure exerted upon that portion of the surface of the bore around the seat of the charge, in firing a 10-inch gun with service charges and solid shot, cannot be less than 50000 lbs. per square inch.

The weight of a body that would produce this amount of statical pressure, per square inch, on the area of a cross section of the bore of that gun, would $= 78.54 \times 50000 = 3927000$ lbs.

This would be the weight of the moving or straining mass necessary to render the remarks, in the discussion above referred to, applicable to a 10-inch gun; whereas, in the discharge of cannon, the charge of powder is the moving mass, and that portion of the gun around the seat of the charge is the resisting mass.

The extensibility of gun iron is, at the highest estimate, not over .004 in. per inch in length. The increase in diameter of the bore of a 10-inch gun would therefore be, at the moment of interior rupture, $= .04$ in., and the extent of radial motion of the surface of the bore would $= .02$ in.

The surface of the bore would have a greater extent of motion than any other part; and if there were no other resistance to motion than the inertia of the mass of the metal around the seat of the charge, the velocity developed in that mass, in passing over a space of .02 in., would be very trifling indeed, and the momentum correspondingly small.

The sum of the moving and resisting masses, in the case of a 10-inch gun, as compared with that of a body whose weight $= 3927000$ lbs., would be very small; nor can the radial velocity of the charge, at the moment when the bore attains the diameter due to the statical pressure exerted upon it, be so great as to render its momentum of any considerable magnitude; from which it follows that, in firing cannon, the excess in strain upon the gun, above that due to statical pressure, caused by the most rapid rate of application, or development of that pressure, is a very small percentage of the total strain.

This reasoning, and the conclusion to which it leads, must not, however, be construed into a disregard of the rate of combustion of the charge, for this is of primary importance; but from causes entirely different from that discussed above.

Experiments indicate that the pressure due to the combustion of gun-powder, in a space equal to it own volume, is not less than 200000 lbs. per square inch; a pressure far greater than can be resisted by any known material.

With a given mass of shot free to move, and a given charge of powder to move it, the more rapid the rate of combustion of that charge, the less distance will the shot have moved during the time of combustion, and the nearer will the pressure developed approach that due to the combustion of powder in its own volume. And the fulminates, and very fine-grained quick powder, behind heavy projectiles, so nearly approach this condition, as to burst the gun before the shot has had time to move; not from the momentum with which the straining and resisting masses reach their position of statical equilibrium, but from absolute statical pressure.

Of the Difference in Effect due to Difference in the Times of Action of a Given Force.

This subject has already been more than once referred to, but not in such a manner as to attach to it that degree of importance to which it is believed to be entitled.

It is well known and understood in architecture and practical mechanics, that a given beam of wood, or bar of iron, will sustain for a limited time a weight which would be certain, ultimately, to break it; and, in general terms, that the rupturing force is a decreasing function of the time required for it to produce rupture.

It is believed, however, that we have not heretofore properly appreciated the effect of time on the resistance which a body can offer, where the *absolute* difference in the times of action is small, but where the *ratio* of the maximum to the minimum time of action is very great. For example, the time required to rupture a tensile specimen of cast iron on the testing machine is, say five minutes. This is a small absolute space of time, and the difference between this and any smaller space must be still less; but as compared with the length of time during which the maximum pressure is exerted upon the bore of a gun at a single discharge, it becomes very great; probably as great as the ratio of the time of existence of any known structure of either wood or iron to that required to test the strength of a single specimen of either material. And if so, why should not the resistance of a gun or shell, to a single dis-

charge, be as much greater than indicated by the test specimen, as the permanent architectural load required of any material is less than that indicated by the test specimen?

The results of different experiments which I have made, indicate that such is the fact. For example, in bursting cylinders with powder, (see page 192, Report of 1860,) set No. 1, with a thickness of metal of .5 inches, gave a bursting pressure per square inch = 37842 lbs., and requiring a tensile strength of iron = 75684 lbs. per square inch, while the tensile strength of the iron by the testing machine was only 26866 lbs.

And in set No. 4, (same page and Report,) with two inches thickness of metal, the bursting pressure was 80229 lbs. per square inch, while the most that it could have been by the testing machine would be twice the tensile strength, or 53732 lbs.

These same results, as well as others, show important differences in resistance due to differences in time of action, when the *greatest* duration was so small as to be entirely inappreciable to the senses. Take, for example, sets Nos. 1 and 2, of the same cylinders just referred to.

These sets were both of the same interior capacity, same metal, as near as could be, and were burst by equal charges of powder of the same quality. Set No. 1 was .5 in. thick, and set No. 2 was 1 inch thick. The mean bursting pressure of set No. 1 was 37842 lbs. per square inch, while set No. 2 was only 38313 lbs.

One cylinder of set No. 2 required two charges to burst it, the indication of pressure being something less for the second than for the first charge.

Now the only and true explanation of these results is believed to be, that 38313 lbs. was the pressure due to the combustion of the charge of powder used, in the space in which it was burned; that it did not greatly exceed the resisting power of the cylinder of set No. 2, and required a greater, though still inappreciable, length of time to produce rupture, (as indicated by the fact of one cylinder forcing the whole products of combustion of one charge out through a hole one-tenth of an inch in diameter, without bursting,) while it greatly exceeded the resisting power of set No. 1, and consequently burst that set in much less time, but not before almost the full pressure due to the charge of powder used, had been developed.

Another example occurs in bursting shells with powder, (see page 206, Report of 1860,) where a shell of 5 inches interior diameter, and 6.5 in. thick, burst

at 42500 lbs. per inch, before the gas evolved from a volume of powder equal to half its interior capacity could escape through a hole one-tenth of an inch in diameter ; while another shell 3.85 in. interior, and 12 inches exterior diameter, resisted the pressure due to the combustion of its entire capacity of powder, up to 185000 lbs. per square inch.

Now the difference in the times of action of the forces in all these examples was entirely inappreciable to the senses, yet the *ratio* of the greatest to the least must have been very considerable.

And in the ordinary discharge of cannon the gun is subjected, at each discharge, to a force which would inevitably burst it, if permitted to act for any appreciable length of time ; so that it may be said that cannon do not burst because they have not time to do so before the bursting pressure is relieved.

The very short duration of the maximum pressure also renders important the *inertia* of the *mass* of the gun around the seat of the charge ; as I have no doubt that an increase of mass in this part of the gun, provided it introduce no injurious strain, would increase its endurance.

The above results and conclusions indicate that it is highly desirable, if practicable, to adopt a standard of time for the action of the rupturing force, in testing the strength of any material ; as I doubt not that many apparent discrepancies in the strength of the same material, by different experimenters, may be due to the difference in the length of time occupied in producing rupture.

Experiments with Powder of variable Diameter of Grain.

For the purpose of further determining the relation between the maximum pressure of gas, and the velocity of shot, due to equal charges of powder, of the same quality in all respects, except in diameter of grain, the following series of fires was made with the 11-inch gun, prepared as heretofore explained, and the same cylindrical shot as was used in the previous experiments with that gun.

The following table exhibits the results obtained :—

Number of Fires.	Size of Grain.	Weight of Charge.	Weight of Shot.	Velocity of Shot.	PRESSURE OF GAS, IN POUNDS.		
					At bottom of bore.	At 14 in.	At 28 in.
1	.6 in.	12.67 lbs.	186.3 lbs.	956	24970	9270	6430
2	.6	12.67	186.3	1073 *	20600	11580	11330
3	.6	12.67	186.3	956	20340	9270	7720
4	.6	12.67	186.3	953	20080	10300	8240
5	.6	12.67	186.3	870	20850	11330	6430
Mean, .	. . .	. . . .	. . . .	933	21370	10350	8030
1	.5 in.	12.67 lbs.	186.3 lbs.	991	21100	12360	6430
2	.5	12.67	186.3	890	22910	12360	7210
3	.5	12.67	186.3	899	21100	11330	7460
4	.5	12.67	186.3	950	20850	9270	7710
5	.5	12.67	186.3	Failed.	20080	10550	7710
Mean, .	. . .	. . . .	. . . .	932	21210	11170	7300
1	.4 in.	12.67 lbs.	186.3 lbs.	890	28840	10800	7210
2	.4	12.67	186.3	811	24720	10300	7210
3	.4	12.67	186.3	955	24720	10300	7210
4	.4	12.67	186.3	889	22910	13900	8240
5	.4	12.67	186.3	860	26780	8490	6430
Mean, .	. . .	. . . .	. . . .	881	25590	10750	7260
1	.3 in.	12.67 lbs.	186.3 lbs.	942	33990	10300	6430
2	.3	12.67	186.3	882	30900	8490	6430
3	.3	12.67	186.3	847	24720	10300	6680
4	.3	12.67	186.3	877	39140	11070	6180
5	.3	12.67	186.3	904	47890	13390	7710
Mean, .	. . .	. . . .	. . . .	890	35330	10710	6680
1	.3 in.	12.67 lbs.	186.3 lbs.	1037 *	61800	10800	7210
2	.3	12.57	186.3	1087 *	67980	16480	8240
3	.3	12.67	186.3	912	67980	16990	9520
Mean, .	. . .	. . . .	. . . .	912	65920	14750	8320

* Target wire cut by cartridge block ; not included in mean.

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TABLE *showing the velocity of shot, in feet, per second, and the pressure of gas, per square inch, in pounds, due to equal charges of powder, of the same composition, and differing only in size of grain—each result being the mean of five fires with the* 11-*inch gun, the same shot being used in all the fires.*

Diameter of Grain.	Weight of Charge.	Weight of Shot.	Velocity of Shot.	PRESSURE OF GAS, IN POUNDS.		
				At bottom of bore.	At 14 in.	At 28 in.
.6 in.	12.67 lbs.	186.3 lbs.	933	21370	10350	8030
.5	12.67	186.3	932	21210	11170	7300
.4	12.67	186.3	881	25590	10750	7260
.3	12.67	186.3	890	35330	10710	6680
.3*	12.67	186.3	912	65920	14750	8320

* Powder of 1859, but not so hard pressed as that of 1860.   Mean of three fires, housing having blown out of gun at the 3d fire, thus preventing a greater number.

Respectfully submitted.

T. J. RODMAN, *Capt. Ord.*

WATERTOWN ARSENAL, April 23, 1860.

REPORT

TRIAL OF

10-INCH GUNS, Nos. 362 AND 363.

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REPORT

OF

TRIAL OF 10-INCH GUNS, NOS. 362 AND 363.

In addition to the 2450 service and 2 proof charges, to which each of these guns had been subjected at Pittsburg, they have each been fired, at the Fort Monroe Arsenal, by Capt. A. B. Dyer, 1632 rounds with 18 lbs. of powder and a solid shot, making a total of 4082 service and 2 proof charges for each gun; neither gun broken.

The cracks referred to in the solid cast gun (page 125) were considerably increased by the additional firing; one, at the conclusion of the firing, extending from the interior of one of the vents almost to the axis of the gun.

The solid gun continued to deteriorate more rapidly than the hollow one, being much more, and more irregularly, enlarged and cut away by the gas, around the seat of the shot. The accompanying diagram, received from Capt. A. B. Dyer, (Plate 1,) shows the profiles of the elements of the bores, in vertical planes, after the above named number of fires.

The right lines, in black, show the original lines of the bores. The irregularly curved lines, in red, show what would be the intersection of the surface of the bore of the hollow cast gun by a vertical plane through its axis, in its present deteriorated condition, and the irregularly curved lines in blue show the same for the solid cast gun.

Owing to the greater enlargement and consequent increase of windage of the solid, than of the hollow cast gun, the latter has, for the last 2000 rounds, been subjected to a greater pressure of gas at each discharge, than the former. A short time before the suspension of the trial a mean of 19

rounds, from each gun, with equal charges (18 lbs.) of the same quality of powder, and one solid shot, showed the maximum pressure at each discharge to be for the hollow gun 39793 lbs. per square inch, and that for the solid gun 35306; or that the hollow cast gun was subjected, at each discharge, to a pressure 4487 lbs. per square inch greater than that to which the solid cast gun was subjected.

These pressures are both far below those due to the same charges, fired in a new unenlarged gun; recent experiments having shown that with 18 lbs. of Dupont's No. 10 experimental powder, common cannon, and one solid shot, from a 10-inch gun, the maximum pressure per square inch was, for a mean of 4 fires, 71950 lbs.

REPORT

INSPECTION, TRANSPORTATION, MOUNTING AND TRIAL

15-INCH GUN.

REPORT

INSPECTION, TRANSPORTATION, MOUNTING AND TRIAL OF THE 15-INCH GUN.

Inspection.

This gun was completed early in May, 1860, when it was carefully inspected. The casting appeared to be perfectly sound in all its parts, the finished surfaces, both of the exterior and of the bore, being remarkably perfect.

The dimensions of the gun are as follows, viz. : —

Lengths.

Total length of gun, ...	190 inches.
From axis of trunnion to rear of breech, . .	71.3
Length of trunnions, ...	6.5
" of cylinder of bore, ...	156.
" of ellipsoidal termination of bore, . .	9.
" from face of muzzle to maximum diameter,	155.
Distance between rimbases, ...	48.1

Diameters.

Maximum diameter, ...	48.1
Diameter of muzzle, ...	25.
" of bore, ...	15.
" of cascable, ...	41.5
" of trunnions, ...	15. .
" of vent, ...	.2
Width of ratchet, ...	6.
Depth of "	1.
Estimated weight of gun, ...	49099 lbs.
Preponderance at ratchet about, . . .	1200

The bore of this gun was remarkable for the smoothness of its surface, and the uniformity of its diameter, the star gauge not showing a variation, from 15 inches, of so much as one-thousandth of an inch in the whole length of bore.

Transportation.

For this purpose two strong trussed beams, 50 feet long, were prepared. These beams were placed parallel to each other, and about 36 inches apart, their ends resting upon two bolsters placed transversely across the middle points of two 8-wheeled platform cars. The gun was suspended under the two trussed beams, and between the cars; so that its weight was equally distributed over the 16 wheels of the two cars.

Thus mounted, it passed over the Pennsylvania Central Railroad to the Susquehanna River, thence on the Northern Central to Baltimore, and thence by the Washington Branch to Washington City, where it arrived in perfect order without change of cars. Speed of cars from 12 to 15 miles per hour.

The gun was hauled from the Washington Depot to the Potomac River on a truck wagon, used for hauling heavy stones, where it was shipped on board a vessel used for carrying heavy stones for the Capitol and Treasury Extensions. From this boat it was landed at Fort Monroe, Old Point Comfort, Va., where it was mounted for trial.

Mounting.

This gun was mounted for trial on a wrought iron carriage, designed by Capt. A. B. Dyer, and built under his supervision at the Fort Monroe Arsenal.

The carriage was of the form and style of the Columbiad barbette carriage, having its pintle in the middle transom of the chassis.

The platform, on which the carriage was placed, was formed by excavating the sand on the sea-beech to the depth of about 2 feet, and filling in the cavity thus formed with concrete; on this concrete, after it had perfectly set, was placed a layer of cut stone, about 15 inches thick, to which the traverse circles were bolted.

The chassis was inclined, so that the gun and carriage, in recoiling, ascended at an angle of three degrees with the horizon. The maximum elevation of the gun, attainable on this carriage, was 28° 35′. The first trials were made with but one pair of traverse wheels under the front end of chassis, the wheels being of cast iron.

A few fires at the maximum elevation, and with the gun pointed in the same direction, sufficed to split both the front traverse wheels in two. These were replaced by another pair of cast iron wheels, banded with inch thick wrought iron bands; and an additional pair of wrought iron wheels was placed as close as practicable to, and in rear of the others, an inner traverse circle being laid down to receive this pair of wheels. Diagonal braces were also added to the chassis and to the top carriage. With these additions this carriage stood all the subsequent firing of this gun, working perfectly well, and with much greater facility than had been expected.

Trial.

The firing was commenced with 25 lb. charges of large grained (.6 in. diameter) powder, and shells weighing 320 lbs., strapped to oak sabots weighing 11 lbs. The charges were increased, as the trial proceeded, by increments of 5 lbs. up to 40 lbs. of the large grained powder, and as high as 50 lbs. of the perforated cake; the maximum pressure of gas being determined for each increment of the grained powder, and that due to 40 lbs. and to 50 lbs. of the perforated cake.

The following table shows the mean results obtained : —

Number of Fires for each result.	Kind of Powder.	Weight of Charge.	Weight of Shell and Sabot.	Pressure of gas per square inch, in lbs.
5	.6 in. grain.	25 lbs.	330 lbs.	8940
5	.6	30	311	10020
3	.6	35	330	13133
3	.6	40	311	18833
5	Perforated cake.	40	330	3280
3	" "	50	325	8000

The charges of perforated cakes had generally from 3 to 5 lbs. of large grained powder in the bottom of the cartridge, to render the ignition of the charge more certain, which is included in the weight of charge given in the table.

For the purpose of comparing the ranges and maximum pressures due to different kinds of powder, with each other, and with those obtained from the 15-inch gun with .6 in. grain, and with the perforated cake, 22 rounds were fired with solid shot of 126 lbs. weight from a 10-inch gun, with the mean results recorded in the following table : —

Name of man-ufacturer of powder.	Kind of powder.	No. of fires for each result.	Weight of charge.	Elevation.	Maximum pres-sure of gas per square inch, in ponnds.	Range in yards.	Time of flight.
Dupont.	No. 2.	4	16 lbs.	10°	14475	2428	10.05″
"	" 10.	4	16	10	71950	2882	11.16
"	" 2.	1	16	30	15000	4335	23.00
"	" 10.	1	16	30	65000	5283	24.53
	Perf'd cake.	1	20	30	9000	4845	21.30
Dupont.	.6 in. grain.	1	16	30	14800	4820	21.65
Hazard.	No. 2.	1	16	30	31000	4860	Lost.
"	Cannon, 1859.	1	16	30	57000	5130	"
"	"	4	16	10	52000	2847	11.09″
"	No. 2.	4	16	10	43725	2796	10.67

Corresponding Results from the 15-inch Gun.

Name of manufac-turer of powder.	Kind of powder.	Number of fires for each result.	Weight of charge.	Weight of shell and sabot.	Elevation.	Maximum pressure of gas per square inch, in pounds.	Range, in yards.	Time of flight.	Recoil, in inches.
—	Perforated cake.	3	50 lbs.	345 lbs.	28° 35′	8000	5208	26.43″	60.
Dupont.	.6 in. grain.	3	40	330	28° 35′	18833	5088	26.37″	61.
"	.6 "	3	35	328	6° 00′	13133	1976	6.93″	70.5
"	.6 "	1	35	330	28° 35′	—	5070	27.25″	58.

The maximum pressures recorded in the last of the foregoing tables were not all determined from the identical same fires, from which the ranges and other results were obtained, but from the same number of other fires with the same charges of the same kind of powder.

The No. 2 powder, of both Hazard's and Dupont's make, was of about the same size of grain as that used in firing the 15-inch gun (.6 in. diameter). The No. 10 powder was of about the same size of grain as common cannon powder.

The .6 in. grained powder, used in firing the 15-inch gun, was of Dupont's make, and was purposely harder pressed than the ordinary powder; his experimental powder used in firing the 10-inch gun for the foregoing results was also much harder pressed than that of Hazard's make.

The greatest range yet obtained with the 15-inch gun was with 40 lbs. of

.6 in. grained powder, and = 5730 yards. This, however, is not the greatest range attainable from this gun ; but as guns of this calibre are intended rather for direct fire at short ranges, than for curved fire at great distances, it was deemed advisable to first determine whether or not it was capable of enduring a satisfactory number of such charges as would likely be fired from it in actual service.

The results in the foregoing tables show the ranges of the 15-inch gun, with 35 lbs. of .6 in. grain powder, to be about the same as those of the 10-inch gun, with 18 lbs. of powder, at corresponding elevations. These ranges require as high velocities, it is believed, as will be ordinarily required from guns of this calibre.

After this gun had been fired 40 rounds, with charges varying from 25 to 40 lbs., a mixed Board of Engineer, Ordnance and Artillery Officers, was appointed by the Secretary of War to witness the further firing, and to "report as to whether or not the efficiency of our present Armament for harbor defence would be improved by the addition of a judicious proportion of guns of this class."

The Board was composed of the following named Officers, viz. : —

General J. G. TOTTEN,
Major J. G. BARNARD, } of *Engineers.*
Captain H. G. WRIGHT,

Major J. SYMINGTON,
Captain A. B. DYER, } of *Ordnance.*
Captain J. GORGAS,

Colonel J. DIMICK,
Major R. ANDERSON, } of *Artillery.*
Captain J. H. CARLISLE,

Lieutenant G. TALLMADGE, *4th Artillery, Recorder.*

The firing before this Board embraced 49 rounds from the 15-inch gun, with full charges, and the 22, before referred to, from a 10-inch gun. Ten rounds were fired for accuracy at 2000 yards, with the results given in the following table, viz. : —

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| Number of fires. | Weight and kind of charge. | Weight of projectile and sabot. | Elevation. | Range, in yards. | Time of flight. | Deviation. | | Recoil, in inches. |
						Right.	Left.	
1	35 lbs., .6 in. grain.	317 + 11 lbs.	6°	2017	7.00″	1 yard.	–	72
2	35 .6 "	317 + 11	6	1937	7.00	3	–	70
3	35 .6 "	317 + 11	6	1902	6.30	$\frac{2}{3}$	–	69.5
4	35 .6 "	317 + 11	6	1892	6.35	5	–	67.5
5	35 .6 "	318 + 11	6	1873	6.55	–	5 yards.	70
6	35 .6 "	317 + 11	6	1973	7.00	2 yards.	–	69
7	35 .6 "	317 + 11	6	1970	6.75	$\frac{2}{3}$	–	68
8	35 .6 "	317 + 11	6	1979	7.00	6	–	77
9	35 .6 "	317 + 11	6	1888	6.80	1.5	–	70
10	35 .6 "	318 + 11	6	1930	7.00	4	–	72

The target at which this firing was done, was simply a stake driven into the ground, with a small red flag attached to its upper end, to render it visible. The elevations were measured with a gunner's quadrant, having a spirit level attached, and the horizontal sighting was done with a straight edge, held as near as could be judged by the eye, in the vertical plane of the axis of the gun, and a chalk mark on the upper element at the muzzle.

The axis of the gun was about 8 feet above the plane on which the shells struck.

When firing at the target, the ranges and lateral deviations from a line joining the gun and target, were measured on the ground. All ranges above 2500 yards were plotted from observations, on the columns of spray thrown up by the plunge of the shell into the water, made with two plane-tables placed at the extremities of a base line of 1900 yards.

The times of flight were measured with a stop chronometer, reading hundredths of a second.

The mean of the above ten ranges is 1936.1 yards, and the mean time of flight 6.775″; the mean velocity in feet would therefore $= \dfrac{1936.1 \times 3}{6.775″} = 857$ feet per second.

Some trials were made to determine the initial velocities of the shells fired from this gun, with M. Navez's electro-ballistic pendulum; but the results were so irregular as to be wholly unreliable, and its further use was abandoned.

An approximation to the initial velocity was then made by firing the gun with the bore horizontal, and measuring the fall of the shells in passing over a known distance. The shells were fired through a board screen at 885 feet

from the muzzle of the gun. This distance, divided by the time required for a body to fall from the height of the axis of the gun to the centre of the hole in the screen made by the shell, would give the mean velocity of the shell in passing over this distance.

The velocity thus determined was, for a mean of 2 fires, with 40 lbs. of large grained powder, and shells of 300 lbs., and rope grommets instead of sabots = 1328 feet per second; and for a mean of 3 fires with 50 lbs. of perforated cakes, and shells of 315 lbs., and rope grommets instead of sabots, the velocity was 1282 feet per second.

One fire with 35 lbs. of large grains, shell 318, and 11 lb. sabot, gave a velocity of 1135 feet per second.

Four rounds were then fired with 40 lb. charges of large grained powder, at 10° elevation, with the following results, viz. : —

Order of fire.	Weight of shell and sabot.	Range, in yards.	Time of flight.	Recoil, in inches.
1st,	315 + 11 lbs.	2700	11.48″	78
2d,	337 + 11	2910	11.30	85
3d,	319 + 11	2754	10.80	78
4th,	319 + 11	2760	11.06	78
Mean,	. . . . .	2781	11.16″	79.75

The above results give the mean velocity of the shell = 747 feet per second. The greatest recoil obtained was, with 40 lbs. of .6 in. grained powder, gun horizontal, = 90 inches.

Trials for Ricochet on Water.

In these trials the gun was 13.5 feet above the surface of the water, and was fired 5 times with 40 lb. charges of large grained powder, and 318 lb. shells, with 11 lb. sabots, with the following results, viz. : —

1st fire, 5° elevation, range 2085 yards, no ricochet.
2d fire, gun horizontal, range 1785 yards, 3 ricochets.
3d fire, gun horizontal, range 1781 yards, 4 ricochets.
4th fire, 5° elevation, range lost, no ricochet.
5th fire, 1° elevation, range lost, 4 ricochets.

The surface of the water was not smooth, nor *very* rough, during this trial;

but the results indicate that lighter projectiles, moving with higher velocities, are better adapted to ricochet firing.

Loading and Manœuvring.

The method of loading was as follows, viz. : —

One man placed the shell hooks upon the shell, the hooks taking into .6 in. holes bored .6 in. deep at the extremities of a diameter perpendicular to that through the fuze hole, another inserted a handspike through the ring of the shell hooks; then four men, two at each end of the handspike, raised up the shell, carried it up the ramp, and held it opposite the muzzle of the gun, while a fifth man revolved it upon the shell hooks and inserted the sabot into the muzzle, pushing the shell in till the hooks came against the face of the muzzle; the hooks and handspike were then taken away by one man, while the other four rammed the shell home.

Three men *could* load this gun, two carrying the shell, and holding it opposite the muzzle, while the third inserted it, as above described; but five is the proper number for this purpose.

The time occupied by seven men in running the gun to battery, depressing it from maximum elevation, sponging, loading, and elevating ready to fire at maximum elevation, was for the first trial 4′, and for the second 3′ 10″.

With the gun horizontal, the time of running it to battery, sponging and loading, was, for the first trial, 1′ 52″; for the second, 1′ 28″; for the third, 1′ 10″; for the fourth, 1′ 15″; for the fifth, 1′; and for the sixth, 1′ 3″.

The time occupied in traversing the gun through an angle of 90° by the same seven men, (one sergeant and six negroes) was 2′ 20″; and in traversing back 45°, the time was 1′. Two men *could* run the gun to battery, but four is the proper number for this purpose; and four *could* run it from battery, but eight is the proper number.

To determine the effect of the explosion of a loaded shell from this gun, one round was fired with 8 lbs. large grained powder, and shell of 117 lbs., containing 17 lbs. of cannon power, elevation 28° 35′. The shell fell on the beech 1430 yards from the gun, and exploded in the sand, forming a crater 40 inches deep, 12 feet long, and 10 feet wide. This concluded the firing before the Board, and the bore of the gun was then carefully examined with

the Star Gauge, but no enlargement above its original diameter could be detected in any part.

The following is an extract from the Report of the Board: —

" Considering, therefore, the inappreciable injury which the 15-inch gun has sustained from the trials to which it has been subjected, and the facility and rapidity with which it was manœuvred and fired, the Board is decidedly of opinion that the introduction of guns of much larger calibre than any now in the service, is desirable and practicable.

" Before, however, the actual adoption of such a class of guns, the Board think that a series of experiments should be made to test fully their endurance and their effect upon targets made after the manner of ships' sides and floating batteries, with and without the iron clothing.

" Qualified by the above remark, the Board, therefore, in the words of the order under which they are acting, report that, in their opinion, ' the efficiency of our present armament for harbor defence would be improved by the addition of a judicious proportion of guns of this class.' "

On the receipt of the Report of the Board, the Secretary of War directed the proof of the gun to be continued, with service charges, till the number of rounds fired should reach 500. Accordingly the firing was resumed on the 18th of December, 1860, and continued with 35 lb. charges, .6 in. grained powder, till a total of 200 rounds had been fired, when the bore was again carefully examined, without detecting any enlargement.

An impression of the interior of the vent was taken, which showed it to be of a nearly regular elliptical form, the greatest diameter being .4 in., and the least .3 in. The exterior of the vent was not perceptibly enlarged.

The firing was then continued with the same charges and kind of powder, till 77 additional rounds had been fired under my supervision; when, in order to enable me to proceed with the preparatory tests of metal for, and to supervise the casting of the 12-inch Rifle Gun at Pittsburg, Captain A. B. Dyer kindly volunteered to continue the firing for me.

The firing was continued with 35-lb. charges, and a shell, till 356 rounds had been fired. Several series of firing were then made, for the purpose of determining the initial velocities of shells, the maximum pressure of gas, the ranges and times of flight, at different elevations, due to charges of .6 in. grained powder varying from 35 to 50 lbs.

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The pressures of gas were determined by means of the internal pressure gauge, and the initial velocities by Captain J. G. Benton's electro-ballistic pendulum, which Captain Dyer represents as giving very satisfactory results.

The results obtained by Captain Dyer from these series, are given in the following tables : —

TABLE *showing the initial velocity and maximum pressure of gas, due to different charges of .6 in. grain powder.*

Number of fires for each result.	Kind of powder.	Weight of charge.	Weight of shell.	Elevation, in degrees.	Range, in yards.	Time of flight.	Initial velocity of shell, in feet, per second.	Pressure of gas per square inch, in pounds.	Recoil of carriage.
11	.6 in. grain.	35 lbs.	300 lbs.	–	–	–	902	–	–
10	.6	40	300	–	–	–	949	–	–
5	.6	45	315	25° 00′	4595	23.24″	–	12528	58 in
4	.6	45	315	–	–	–	1064	–	–
4	.6	50	315	–	–	–	1118	–	–
5	.6	50	315	25° 00′	4686	23.29″	–	12568	–

TABLE *of ranges of shells fired from the 15-in. gun, at different elevations.*

No. of fires for each result.	Kind of powder.	Weight of charge.	Weight of shell.	Elevation, in degrees.	Range, in yards.	Time of flight.	Recoil of carriage.
5	.6 in. grain.	40 lbs.	301 lbs.	0° 00′	273	.88″	–
5	.6	40	302	1 00	484	1.66	–
5	.6	40	302	2 00	812	2.49	–
5	.6	40	300	3 00	1136	3.43	–
5	.6	40	300	4 00	1310	4.37	–
5	.6	40	302	5 00	1518	5.07	–
4	.6	40	302	6 00	1760	5.96	–
5	.6	40	298	7 00	1948	7.11	–
5	.6	40	315	8 00	2194	8.17	35.5 in.
5	.6	40	315	9 00	2236	8.87	30.5
6	.6	40	315	10 00	2425	10.00	32.95
5	.6	40	315	12 00	2831	12.07	30.5
5	.6	40	315	15 00	3078	13.72	47.25
5	.6	40	315	20 00	3838	17.82	46.6
5	.6	40	315	25 00	4528	22.03	43.6
6	.6	40	315	28 00	4821	24.18	40.75
6	.6	40	315	30 00	5018	26.71	23.16
2	.6	40	330	30 00	4832	25.55	25.5
5	.6	45	315	25 00	4595	23.20	62.45
5	.6	50	315	25 00	4686	23.29	65.65

This gun has been fired 505 rounds with full charges, and 4 rounds with smaller charges.

It will be seen that the maximum pressures, and the ranges, for corresponding charges and elevations, are something less in the foregoing tables than those obtained from the firing before the Board. This is due to the greater density of the powder used by Captain Dyer than that used by me in firing before the Board.

After 500 rounds had been fired the gun was again carefully washed out and examined with the Star Gauge, and by means of light thrown into the bore, and Captain Dyer informs me that " no wear or enlargement was discovered," and that " the interior of the vent was enlarged, but less than vents usually are after 500 rounds."

These results leave no doubt of the ability of this gun to endure an almost indefinite number of fires, with charges equal to the maximum hitherto fired from it.

It is also certain that much higher velocities, and much greater ranges, than any yet reached with this gun, may be safely attained, as I have the utmost confidence in its ability to endure 1000 rounds with charges giving a maximum pressure of gas double as great as the greatest to which it has yet been subjected; and if the perforated cakes be used in such charges as to give this pressure, the resulting ranges, at the maximum elevation, must be considerably over four miles.

The perfect reliability of this gun, for all the requirements of service, having been fully established by the trials to which it has been already subjected, it is now deemed of the highest importance that the effects of its projectiles, upon masonry, and especially upon iron-clad and steel-clad targets, should be experimentally determined, with the least possible delay: after which it is recommended that it be subjected to a series of firing, with increasing charges, for the purpose of determining the greatest safely attainable range of its projectiles, and the proper diameter of grain powder, and the proper thickness of walls in the perforated cake cartridge, for its ordinary service.

Of the Perforated Cake Cartridge.

This form of cartridge was arrived at from the following principles and theoretical considerations: —

The projecting charge should be so related, in its rate of combustion, to the form of the gun from which it is fired, that, with a given convenient thickness of metal and length of bore, the maximum velocity of shot attainable from such gun should be produced ; or that a given velocity of shot should be produced with the minimum strain upon the gun. This requires that every part of the gun should be subjected to the same proportional strain, or "bursting tendency," at each discharge.

If the resistance which the gun could offer were independent of the length of surface subjected to pressure, as would be the case if the tangential resistance alone were brought into play, the foregoing conditions would require that the pressure of the gas should be uniform throughout the entire length of the bore.

Now let us see in what manner this condition is fulfilled by our present form of cartridge. The most favorable hypothesis that can be made with grained powder, is that the grains are spherical, and of uniform size.

If, now, we suppose the powder to be so hard pressed that the gas cannot permeate the grains, and that the diameters of the grains undergo equal reductions in equal successive portions of time, we shall, at the end of half the time required for its total combustion, have consumed *seven-eighths* of the whole charge, the volumes of spheres being to each other as the cubes of their diameters, while the shot will have traversed only something more than *one-fourth* of the bore, supposing the time required for the combustion of the charge to $=$ that required for the shot to traverse the entire length of bore.

From which we see that with this kind of charge the gas is evolved in the inverse order of what it should be ; the evolution being greatest while the velocity of the shot is least, and least while that velocity is greatest, and giving rise to excessive pressure at and near the seat of the charge, and a too rapid diminution of pressure from that point forward.

This highly objectionable property of grained powder may be remedied, in some degree, by increasing the size of grain, if it be sufficiently hard pressed to render it impermeable to gas under the pressure to which it is to be subjected in firing; for it is clear that the initial burning surface, the maximum pressure, the difference between the mean and maximum pressures, and the difference between the initial and the terminal burning surfaces, will all diminish as the diameter of grain increases.

But to bring the maximum pressure within proper limits, requires such an increase in diameter of grain as to require either an inconveniently long gun,

or an increase of charge, in order to produce the requisite velocities : since for a gun of ordinary length the grains would not be entirely consumed in the gun; and the larger the grain, the *more* of each would be blown out unburned. And in soft, lightly pressed powder, we lose all control over the rate of combustion, the larger grain sometimes giving the greater pressure, owing to the larger interstices causing a more rapid rate of inflammation.

The condition of uniformity of pressure along the entire length of the bore, would be theoretically fulfilled by a cartridge so constructed that ignition should take place only on the inner surfaces of elementary cylinders of constant lengths, and that the combustion of the charge should increase the radii of these cylinders equal quantities in equal successive portions of time; for since, by hypothesis, the radii of the cylinders increase, directly as the times, and since the areas of the cross sections of the cylinders, and consequently the volume of the charge consumed, and of the gas evolved, are to each other as the squares of the radii of the cylinders, it follows that they will also be to each other as the squares of the times.

But the dynamical equation, expressive of the circumstances of motion due to a constant accelerating force, is $S = \frac{1}{2} g t^2$; in which $S =$ space passed over, $g =$ constant force, and $t =$ the time. Or the spaces passed over, (which, in this case, are the volumes of gas, or the spaces behind the shot,) are to each other as the squares of the times.

But experiments on bursting cylinders by pressure exerted upon unequal lengths of bore (page 145) show that, owing to the transverse resistance developed, for short lengths of surface pressed, the resistance which a cylindrical gun could offer to a bursting force would be greater for a length of two calibres from the bottom of the bore, than for one of seven calibres, or any greater length, in the ratio of 3 to 2 ; and the pressures of the gas, at these points of the bore, ought to be to each other in the same ratio. And this requirement may be almost exactly met in practice by establishing the proper relation between the initial burning surface, or between the number and diameter of the cylindrical holes, and the thickness of the walls between them.

The initial burning surface, and the ratio of the maximum to the mean pressure, may also be varied by varying the number and thickness of the cakes in a given weight of charge; the initial burning surface and the

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maximum pressure both increasing with the number of cakes, since the burning surface extends over the whole surface of the cakes.

The thickness of walls between the cylinders, should be such as to be burned through, or consumed, before the projectile leaves the gun; and for ordinary velocities we should economize in weight of charge, by making the walls of such thickness as to burn through by the time the projectile has traversed two-thirds or three-fourths of the bore, and allowing the gas to act expansively from there to the muzzle.

It will readily be seen, from the foregoing, that this form of cartridge gives us entire control over the rate of combustion of the charge, a fact of which the importance can hardly be overrated; for, taken in connection with the hollow mode of casting cannon, it removes all limit, as regards safety, to the calibre, of which even cast iron guns may be made.

In practice, the axes of the cylindrical holes through the cakes are parallel to that of the bore, when the cartridge is in position, and the cakes vary, as hitherto constructed, from one to two inches in thickness; and those used in firing the 15-inch gun were made of Hazard's cannon powder of 1857.

Manner of Forming the Cakes.

The cakes are formed by placing either mealed or grained powder, moistened with about three per cent. of water, in a mould of the proper form, and subjecting it to a pressure such as to render it impermeable to gas, under the pressure to which it will be subjected in the gun. The mould is placed on a bed piece, pierced with the number and size of holes to be in the cake, the holes in the bed piece being covered by a sheet of paper, to keep the powder in the mould from entering them.

A piston, of the same cross section as the interior of the mould, and having screwed into its lower end, and parallel to its axis, the same number of cylindrical wires with conical points, and of the same diameter, as the holes in the bed piece, is mounted at its lower end with a follower, having the same cross section as the mould, and pierced with the same number of holes. This follower is slipped on, over the teeth, till it comes against the end of the piston, and is of such length as to penetrate the mould far enough to give the proper thickness and degree of pressure to the cake. The teeth project through this follower far enough to pass entirely through the loose powder in the mould, and enter the holes in the bed piece, before the follower enters

PLATE II.

Perforated Cake Cartridge
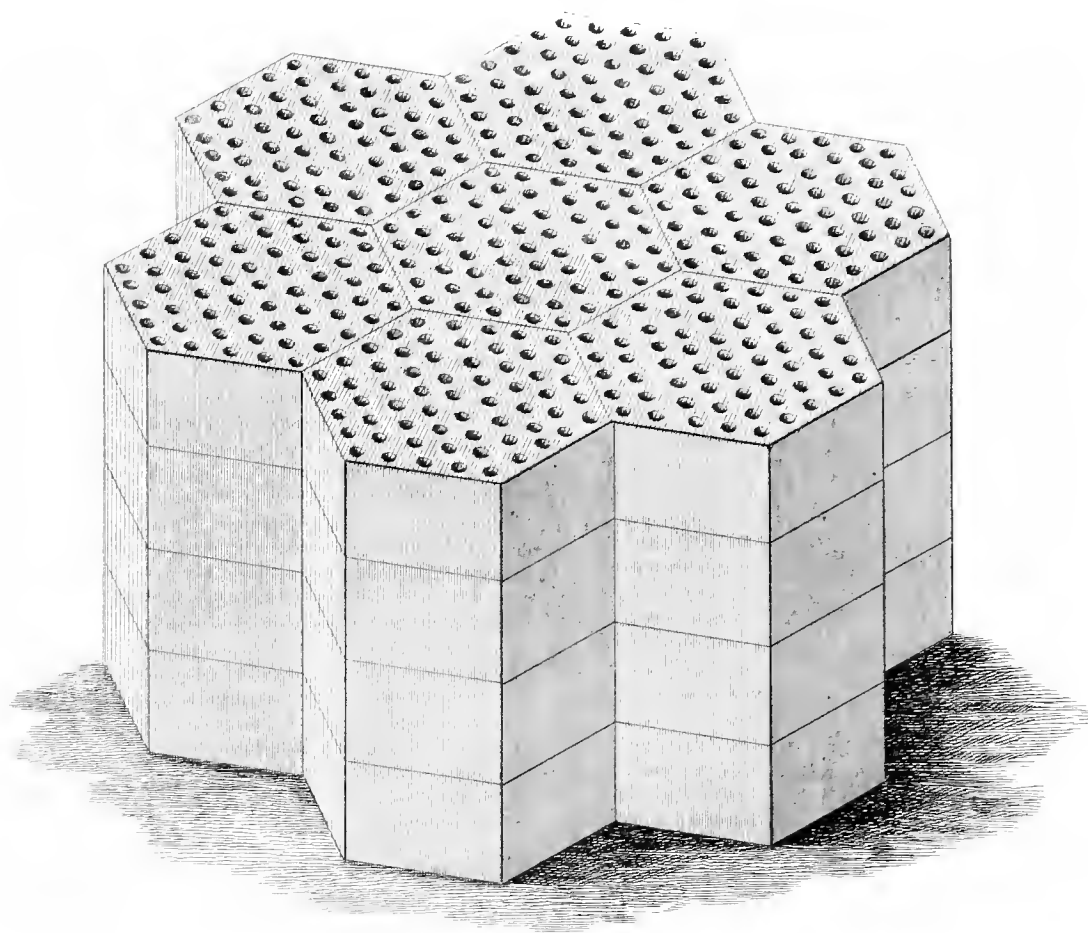
the mouth of the mould. The follower has a shoulder, or ledge, at its upper end, of greater diameter than the body, by means of which it is firmly held in contact with the pressed cake while the wires are being withdrawn.

This prevents the pressed powder at the upper surface of the cake from adhering to the wires as they are withdrawn, and leaves perfectly smooth holes through the cake. The mould is made in halves, which part on a plane through the axis parallel to the axes of the holes. The exterior surface of these halves, when they are together, is slightly conical, and they are held together while the pressure is being applied to the cake, by a strong band.

After the proper degree of pressure has been applied to the cake, and the teeth withdrawn, the mould is turned upside down, the band jarred off, and the cake removed.

A hydraulic press was used in the preparation of the cakes hitherto made ; and for guns of ordinary calibre the cakes can be made of the proper diameter to form, when piled one on another, a cylindrical cartridge, which, when slightly pasted on the exterior, or edges of the cakes, and rolled up in strong paper, makes a very strong compact cartridge.

The press used in the manufacture of the cakes fired in the 15-inch gun, had not the means of extracting the teeth from a compressed cake of so large a diameter. On this account the cakes were made of hexagonal plan, and of such diameter that seven cakes would form one tier in the cartridge. One of these cartridges, four tiers high, is shown on Plate 2.

The proper thickness of walls can only be determined by experiment ; and there is no doubt that the walls were too thick in the cakes fired in the 15-inch gun, for they were seen to burn after leaving the gun ; so that with the proper thickness of wall, or such a thickness that the cartridge should have been wholly burned in the gun, the same velocities might have been obtained with a less weight of charge.

The large grained powder greatly diminishes the strain on the gun in producing a given velocity, from that due to ordinary cannon powder ; and the larger the grain the less will the maximum exceed the mean pressure, and the greater will be the charge required to produce a given velocity.

The large grained powder, owing to its being less costly than the perforated cake, and giving ordinary velocities without *excessive* strain upon the gun, will probably be most generally used ; but for guns of very large calibre, or when extraordinary velocities are required, the perforated cake should be

exclusively used. And as for our common cannon powder, it is too fine grained and too explosive even for field guns, and certainly never should be used for *guns* of larger calibre.

And all powder, of whatever kind, should be sufficiently hard pressed to render it impermeable to gas under the pressure to which it may be subjected in firing.

PROJECTILES FOR GUNS OF VERY LARGE CALIBRE.

Owing to the same property of cast iron, which led to the hollow mode of casting cannon, that of straining itself, sometimes even to rupture, by the contraction which it undergoes in cooling, *solid* shot, of large diameter, cannot be made.

For, in attempting to make a solid shot of cast iron, the cooling *must* be effected wholly from the exterior. The metal will consequently solidify first on the exterior, and thus cut off all chance of supplying fluid metal to the interior, as the cooling and contraction proceed. And after a shell, of such thickness as to resist the contracting force of the interior hotter and weaker metal, shall have formed on the exterior, the interior portions being at a much higher temperature, will have a greater amount of contraction yet to undergo. But owing to their attachment to the now almost incompressible exterior shell, they are partially prevented from undergoing that contraction; and, in their effort to do so, the particles are drawn asunder, and the metal rendered spongy and weak in some cases, ruptured and fissured in others, and quite large, and nearly hemispherical cavities formed, generally in the upper hemisphere, in others.

By revolving the shot, during the process of congelation, the effects of contraction (cavities, fissures, &c.) may be brought nearer to the centre of the shot, and its strength and accuracy of flight thereby improved; but, that a perfectly solid sphere of cast iron, of the proper degree of hardness for cannon shot, of even 8 inches in diameter, has ever been made, I do not believe. I have seen many 8-inch and 10-inch shot broken, in experimental firing, by striking one against another, but have never yet seen one that even nearly approximated perfect solidity.

For these reasons it is believed that for large guns, very thick shells, their thickness being equal to, say, one-third of their exterior diameter, would be more effective against masonry or iron-clad ships, than the so called solid shot.

Their centres of gravity and volume would certainly more nearly coincide,

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and they would consequently be more accurate in their flight. The weight of a 15-inch shell, 5 inches thick, would be about 410 lbs.

Owing to the diminished maximum pressure of gas developed in producing a given velocity of projectile with the large grained powder, and especially with the perforated cake, the tendency of the projecting charge to break the projectile, is also reduced; so that much thinner shells may now be used than heretofore, when the projecting charge was composed of finer grained and more explosive powder.

The shells used in the trial of the 15-inch gun, varied in thickness from 2.5 in. to 3 inches. None ever broke in the gun, but some did break in the sand bank, after the sand had been packed hard by repeated firing.

A 15-inch shell, 2.5 in. thick, will contain about 17 lbs. of powder; and I have no doubt that shells, only two inches thick, may be fired from the 15-inch gun, with charges of perforated cakes, sufficient to throw them over three miles, without danger of their breaking in the gun. A 15-inch shell, 2 inches thick, would contain about 22 lbs. of powder.

Thin shells, containing the maximum charge, would of course be used when the principal effect is intended to result from the explosion of the shell, and thick ones when the object is to batter down masonry, or break through the walls of iron-clad ships or floating batteries.
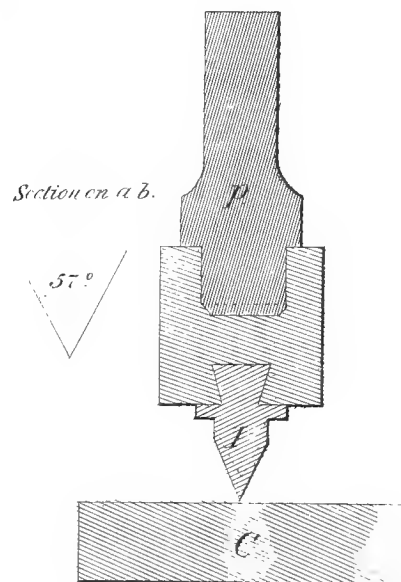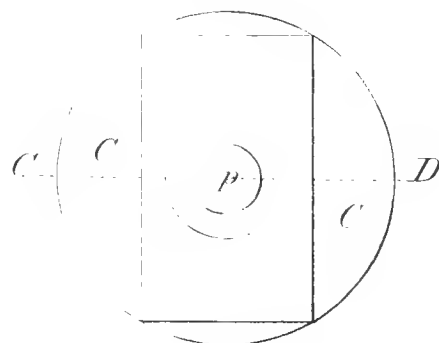
PLATE III.

Internal Pressure Gauge.
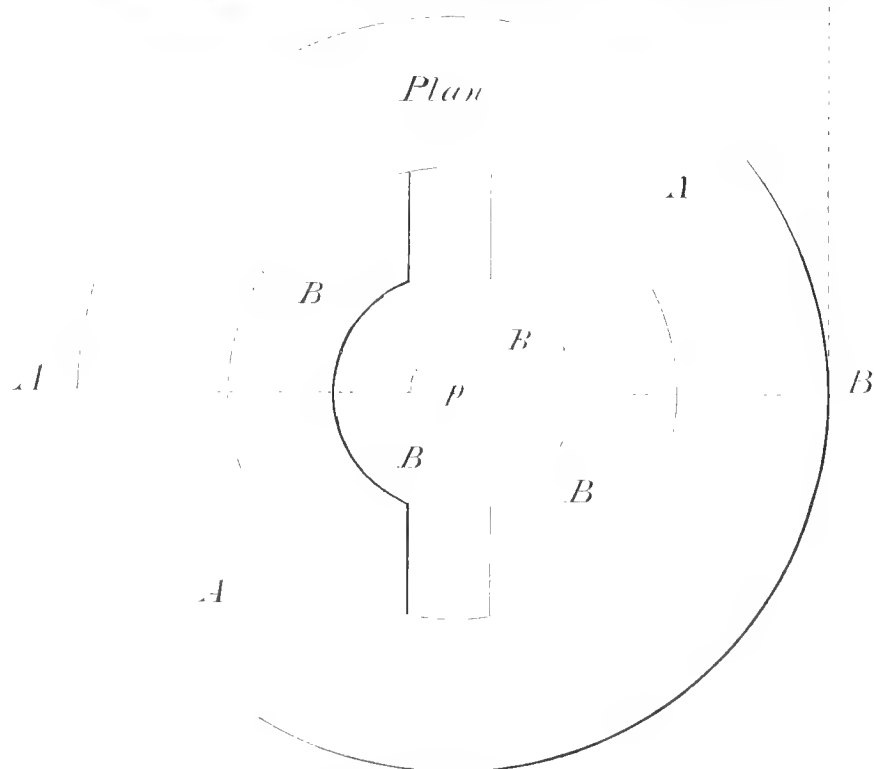## Section on A B.
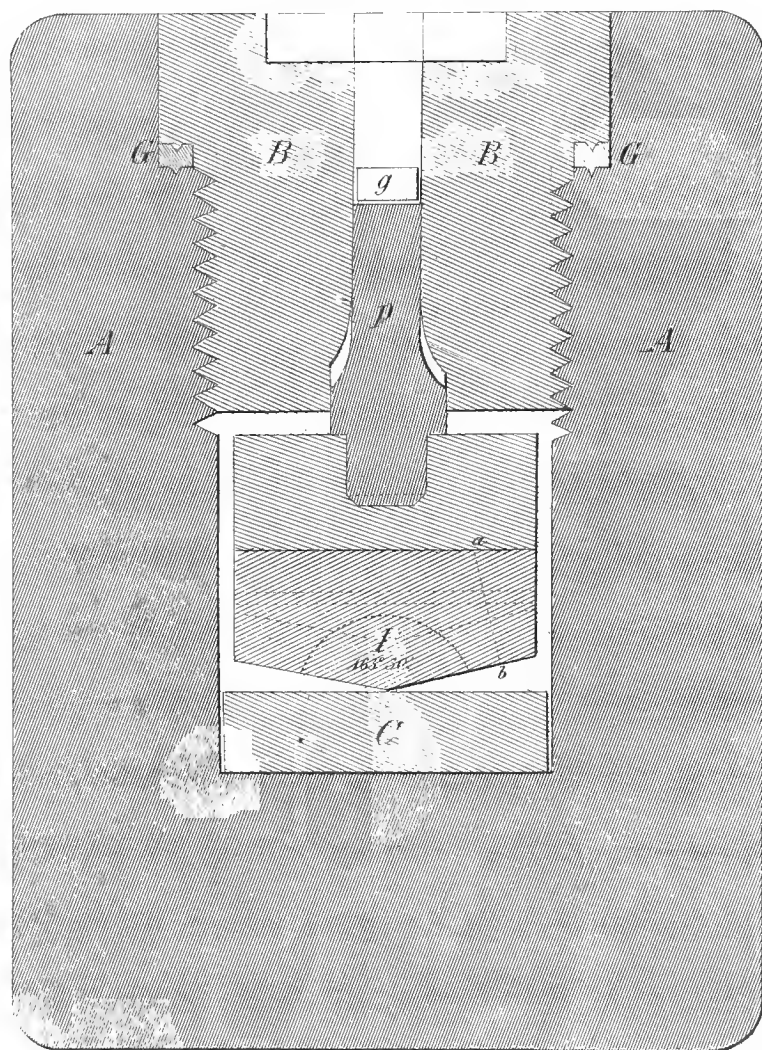
Indenting tool

Section on C. D

Section on a b.

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Plan

Plan

INTERNAL PRESSURE GAUGE.

The pressure of gas in the 15-inch gun was determined by the method of indentations, as heretofore explained, except that the apparatus was placed wholly within the bore of the gun, being inserted in the bottom of the cartridge bag, and having the charge filled in over it, so that no powder should get under it, and come between it and the bottom of the bore, when rammed home in the gun.

The accompanying diagram (Plate 3) shows the construction of this instrument. (A) outer cylinder, (B) screw plug, for closing mouth of outer cylinder, (G) copper gasket to form gas tight joint, (C) specimen of copper to be indented, (I) indenting tool, (p) indenting piston, (g) gas check.

In using this instrument, all its parts, except the exterior of the outer cylinder, are carefully cleaned before each fire, and the threads of the screw plug, and the indenting piston, carefully oiled; the copper specimen is then placed in the bottom of the cylinder, the indenting piston inserted into the screw plug, and, with the outer cylinder horizontal, the plug is screwed home; being afterwards tightly set in with a wrench, while the cylinder is held in a vice. The cylinder is then carefully set down upon its closed end, and the indenting piston gently pushed down till the point of the indenting tool rests upon the copper specimen; a small gas check is then inserted, mouth outwards, till it rests upon the end of the indenting piston. It gives additional security against the passage of gas to place a small wad of cotton or tow over the gas check, *pressing* it in firmly, without *driving*, as a very light blow, several times repeated, might give a greater indentation than that due to the pressure to which it was to be subjected, and thus give erroneous results.

The instrument is inserted into the gun with the screw plug towards the muzzle, and is generally found in the bore of the gun, after its discharge, when the screw plug is withdrawn, and the specimen removed, having an indentation in its surface, due to the pressure that has been exerted upon the outer end of the indenting piston.

The indications of pressure are found to be, generally, something less, for equal charges, by this instrument, than by the external housing; this may be, and probably is, due to the retardation of the rate of inflammation of the charge, by the presence of the instrument, and to the heat absorbed by it.

For these reasons this instrument should be as small as may be compatible with its practical use.

To enable those who have not the means of determining the pressure corresponding to a given length of indentation, to obtain approximate results from the pressure gauge, the following table was constructed, by accurately measuring the length of cut due to each 100 lbs. from 100 to 9000.

The indentations were made *with* an indenting tool of the dimensions given in the plate (No. 3), showing the construction of the pressure gauge, and *in* the same bar of annealed copper.

These results were plotted, and the accompanying mean curve (Plate 4) constructed from them, and from this curve the lengths of cuts given in the table were taken.

TABLE *showing the relation between the pressures and corresponding lengths of indentations in annealed copper from* 100 *to* 9000 *lbs.*

Weight in pounds.	Length of indentations.	Weight in pounds.	Length of indentations.	Weight in pounds.	Length of indentations.
100	.115	3100	.845	6100	1.246
200	.175	3200	.860	6200	1.257
300	.225	3300	.875	6300	1.268
400	.260	3400	.890	6400	1.279
500	.295	3500	.905	6500	1.290
600	.330	3600	.920	6600	1.301
700	.360	3700	.935	6700	1.312
800	.390	3800	.950	6800	1.323
900	.415	3900	.965	6900	1.334
1000	.440	4000	.980	7000	1.345
1100	.465	4100	.995	7100	1.355
1200	.490	4200	1.008	7200	1.365
1300	.512	4300	1.021	7300	1.375
1400	.535	4400	1.034	7400	1.385
1500	.555	4500	1.047	7500	1.395
1600	.575	4600	1.060	7600	1.405
1700	.595	4700	1.073	7700	1.415
1800	.615	4800	1.086	7800	1.425
1900	.635	4900	1.099	7900	1.435
2000	.655	5000	1.112	8000	1.445
2100	.675	5100	1.125	8100	1.455
2200	.695	5200	1.138	8200	1.465
2300	.712	5300	1.150	8300	1.475
2400	.730	5400	1.162	8400	1.485
2500	.747	5500	1.174	8500	1.495
2600	.765	5600	1.186	8600	1.505
2700	.782	5700	1.198	8700	1.515
2800	.800	5800	1.210	8800	1.525
2900	.815	5900	1.222	8900	1.535
3000	.830	6000	1.234	9000	1.545

NOTE. — To obtain the pressure of gas per square inch, divide the pressure given in the foregoing table by the area of a cross section of the indenting piston.

PLATE IV.

Pressures producing indentations

Length of indentations
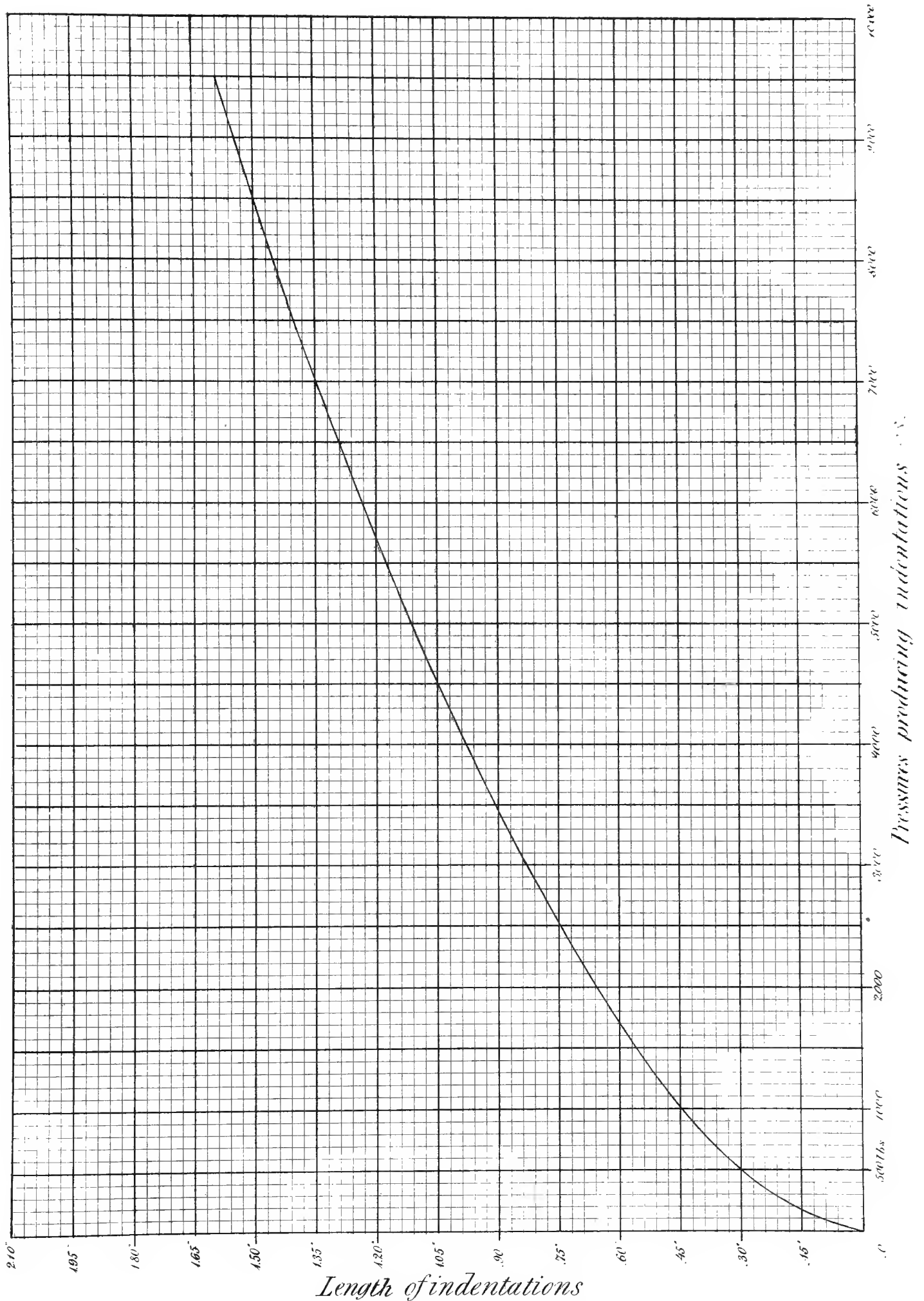
STANDARD QUALITIES OF IRON FOR CANNON.

For every variety of iron there is a certain degree of decarbonization, and a certain rate of cooling, which will, when combined, render the endurance of the gun made from it, a maximum.

This degree of decarbonization, and rate of cooling, will be accompanied by a certain degree of tenacity, extensibility, compressibility and elasticity, which are those properties of iron on which the endurance of guns made from it mainly depends.

That particular combination of these properties, in our best varieties of iron, which imparts to the guns made from them the greatest endurance, is still a desideratum; and one of sufficient importance, it is believed, to fully justify the labor, time and expense which would be involved in its full and accurate determination. And its early determination is earnestly recommended.

The following letter contains my views as to the proper method of determining *standard qualities* for any given variety of iron : —

PITTSBURGH, PA., *December* 20, 1859.

COL. H. K. CRAIG, ORDNANCE OFFICE, }
    WASHINGTON CITY, D. C. }

SIR: The testing machine, last constructed, affords the means of accurately determining those properties of metals on which the endurance of guns is believed mainly to depend.

As yet, however, no standard of properties has been determined, nor is it believed to be practicable to determine such standard, except by connecting the mechanical tests of a metal with the endurance, under the powder proof, of the guns made from it.

With a view, therefore, to determine and establish such a standard as will enable us to predict, with some degree of certainty, the endurance of a gun, from a knowledge of the properties of the metal of which it was made, it is proposed to select, and thoroughly mix, so as to render as uniform in quality as possible, of iron known to require further decarbonization to bring it to

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its maximum endurance when made into a gun, a sufficient quantity for, say five guns, and as many cylinders from which to take specimens for mechanical tests.

Of the iron thus selected, I would work up to what should be believed to be its point of maximum endurance, a sufficient quantity to make one gun and one cylinder, and from it would cast both at the same time.

I would then cast, from the same lot of iron, another gun and cylinder, *further* decarbonized to a certain known degree, and another *less* decarbonized to a known degree.   I would then procure a sufficient quantity of powder, of the same quality, for the extreme proof of the five guns, with service charges; and with it would prove to extremity, by firing them alternate rounds, with equal charges, the three guns made as above described, and determine the properties of the iron in the cylinders cast with them.   The results obtained from these proofs would indicate whether the iron required *further* or *less* decarbonization.

I would follow these indications, and make other guns and cylinders, differing by known degrees of decarbonization, one from another, and from those already proved, until the maximum endurance should be reached. Then the properties of the metal in the cylinder cast at the same time and from the same metal as the gun that gave the maximum endurance, would be *standard properties ;* and from any other iron, giving the same mechanical tests, it would seem reasonable to expect an equal endurance when made into a gun.

This, it is believed, would be the case if it were true that all varieties of iron undergo equal degrees of contraction from equal reductions of temperature.   This, however, is not the case, and *absolute knowledge* would require that each variety of iron should be tested as above described, in order to determine its *own proper* standard of qualities.

The difference in endurance of guns, made of different varieties of iron, giving the same mechanical tests, would be due to the difference in the strain to which the guns would be subjected by the different degrees of contraction in cooling; and of the existence of this cause of difference in endurance the mechanical tests would give no indication, for the reason that the specimens for those tests are relieved from strain by being detached from the mass, of which they formed a part, in casting and cooling.

The strain due to contraction in cooling will increase or diminish the

endurance of a gun, according as it tends to increase or diminish the quantity of metal, or thickness of the gun, brought into useful resistance at each discharge ; and for *any* material that *contracts* in cooling, the strain due to contraction, when cast into a gun, will be injurious when the gun is cooled from the exterior, and beneficial when it is cooled from the interior.

It is not believed to be practicable to cool a gun *entirely* from the interior; but that it may, by the hollow mode of cooling, be relieved from all *injurious strains*, due to contraction in cooling, I have no doubt. Hence the difference in endurance of guns, made of different varieties of iron, giving the same mechanical tests, would be less when the guns were cooled, as far as practicable, from the interior, than when cooled *entirely* from the exterior. I would consequently use hollow cast guns for this experiment.

With a view to derive all the information possible from a given expenditure of money, I would suggest that cylinders for mechanical tests be cast with every gun intended to be proved to extremity; such as the trial guns made by the different founders preparatory to commencing work on an order for guns.

It would add further to the knowledge thus derived, or desirable, if all the trial guns made at the different foundries, near the same time, were brought together for proof, and proved by the same person, by firing them alternate rounds with equal charges of the same powder. This mode of proof would enable us accurately to compare the endurance of the guns thus proved, and would soon give us a much more accurate knowledge of the relative merits of the different varieties of iron of which guns are now made, than we at present possess; and would in time point out with certainty that variety from which the *best guns* are obtained, and from which, when found, all guns should be made.

I am, very respectfully, sir,

Your obedient servant,

T. J. RODMAN, *Capt. Ord.*

In the foregoing letter, iron and powder for the fabrication and proof of only five guns, with corresponding trial cylinders, are specified; and although it is not *probable* that a larger number would be required, yet in entering upon the experiment it would be well to provide materials for a larger number, as it would insure the success of the experiment without adding to its cost, since the unused material would be worth its cost.

SMELTING OF IRON FOR CANNON.

This is a subject, the importance of which, in its relation to the endurance of cannon, has heretofore, especially in this country, been, in my judgment, entirely under-rated.

While officers have been sent to the *foundries* to supervise the *casting* of cannon, the smelting furnace, where the fundamental qualities, and the susceptibility, or non-susceptibility, of being "worked up" to a high standard of excellence, are imparted to the iron, has been almost entirely neglected.

It is in the smelting furnace that the character of the iron is fixed. Iron of good character and high susceptibility *may* be spoiled by its treatment at the foundry; but this, with ordinary experience and intelligence, ought but rarely to occur; and with that degree of care that *should* be bestowed on so important a subject as the manufacture of cannon, it should *never* occur.

But from iron that leaves the smelting furnace with *bad* qualities, I regard it as wholly impracticable, with our present knowledge, to make good and reliable guns. The smelting of iron is a purely chemical process, and should be conducted with the same regularity and precision as any other important chemical process.

There are so many disturbing causes tending to affect its character and qualities that, after every precaution shall have been taken to remove them, *perfect* uniformity, in the quality of the iron produced from day to day, cannot be expected. But that a *much* nearer approximation to uniformity than is ordinarily made, is practicable, I have no doubt.

All the stock for a "blast" of gun iron, should be carefully prepared and *housed* before beginning to "blow." The ore should all be roasted, and well mixed, so as to be as nearly uniform, as to size of lumps, and all other qualities, as possible. The charcoal should all be made, as nearly as possible, from the same kind of wood, and well mixed together after charring. All the stock should be carefully weighed and supplied to the furnace at regular

intervals of time. The pressure, temperature, and hygrometrical condition of the blast, should be kept as nearly constant as possible. The temperature of the blast may be kept very nearly constant, without using what is termed a "hot blast," which should not be used, by warming it just enough to bring it above the highest summer temperature.

The quantity of moisture may, it is believed, be kept nearly constant by passing the blast some distance over water, heated to the proper temperature. And this may be readily done by passing the blast through a long horizontal tube, like a cylindrical steam boiler, partly filled with water, and kept at a constant temperature by the waste heat from the tunnel head.

The temperature of the water should be such as to saturate the blast with moisture, and thus render it hygrometrically independent of atmospheric changes. With these precautions, an intelligent practical smelter in charge of each furnace, a practical metallurgic chemist within consulting distance, zealous and intelligent officers to supervise the whole operation, and whose whole interest should be in making the best quality of gun metal, it is believed that a very close approximation to uniformity in quality of the iron produced would be attained.

Then, supposing a standard of quality to have been determined, with the stock all prepared for a given number of guns, and having determined, by comparison with the *standard*, the quality of iron required, a further approximation to identity in quality of the metal in the *guns* may be made by casting each run of metal from the smelting furnace into a number of pigs, of equal size, something greater than the number of guns to be made, and piling them in separate piles, each run of metal furnishing one pig to each pile.

Each pile should contain iron enough for one gun and one cylinder, and be kept separate and distinct from all others in transportation, and be re-piled in the foundry yard in the same order as at the smelting furnace; one gun being made from each pile, after the treatment which the iron should receive at the foundry shall have been determined by experiments made on the iron in the surplus piles. The pigs should be cast in moulds prepared from a pattern, so as to be as smooth and free from adhering sand as possible.

These precautions I regard as of the utmost importance; for without uniformity in quality of the iron received from the smelting furnace it is

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impossible to make guns of uniform quality. While with that degree of uniformity in the quality of the iron which these precautions would insure, careful treatment of the metal at the foundry, the hollow mode of casting, and powder properly adapted in density and size of grain to the length and calibre of the gun in which it is to be used, I am fully satisfied that perfectly reliable cast iron guns may be made, not accidentally, but certainly and continuously.

A 20-INCH GUN.

The entire success which has attended the manufacture and trial of the 15-inch gun, leaves no doubt of our ability to *make* reliable guns of even greater diameter of bore than 20 inches, and to manœuvre and load with facility, and without the use of machinery, guns of that calibre.

A 20-inch gun, one calibre thick, 210 inch length of bore, and 20 feet total length, would weigh about 100000 lbs.

A solid sphere of iron, 20 inches diameter, would weigh about 1000 lbs. A shell, 20 inches exterior diameter, 6.66 inches thick, would weigh about 925 lbs. The ordinary service shell need not be over 3.5 inches thick; would weigh about 725 lbs., and contain about 38 lbs. of powder, making the total weight of the loaded shell about 763 lbs. Shells only 3 inches thick *may* be fired without danger of breaking in the gun; they would weigh about 657 lbs. each, and contain about 48 lbs. of powder, giving the weight of the loaded shell = 705 lbs.

Adopting the same method of loading as already explained for the 15-inch gun, nine men, four at each end of the handspike, would load this gun with nearly the same facility that five did the 15-inch gun; and seven men *could* load it.

The charge of powder, required to impart the ordinary velocity to one of these shells, would be about 100 lbs.

The living force of the *service* shell would equal that of *six* 10-inch solid shot; and that of the *battering* shell would considerably exceed that of *seven* 10-inch solid shot. And the destructive effect of such shells, as compared with 10-inch shot, upon iron-clad ships and floating batteries, would be in a much higher ratio; their whole crushing force being brought to bear upon a single point at the same time, while that of the smaller shot would be unavoidably dispersed, as regards both time and point of impact.

While, therefore, fully recognizing the principle that the destructive effects of projectiles upon a strongly resisting object, increase in a higher ratio than

as their calibres, and having no doubt that reliable guns of larger calibre may be readily made, yet, from the fact that 20 inches is about the largest calibre that can be readily loaded and manœuvred, without resort to machinery, and because it is not deemed probable that any naval structure, proof against that calibre, will soon, if ever, be built, I propose 20 inches as the calibre next to be tested.

<div style="text-align:center">Respectfully submitted,</div>

<div style="text-align:center">T. J. RODMAN,</div>

<div style="text-align:right">Capt. of Ord.</div>

Watertown Arsenal, April 17, 1861.

ERRATA.

Page 5, in third line describing specimen from cylinder A $\underset{c}{2}$ C, omit "*as*" after the word "specimen."

" 5, in first line describing specimen from cylinder A 2 c, insert "*as*" after the word "cylinder."

" 11, in 26th line, for "*25 inches*," read "*.25 inches.*"

Plate IV., for "*cushing specimens*," read "*crushing specimens.*"

Page 27, opposite Gun No. 160, for "*32 lbs.*" read "*32-pdr.*"

" 28, in 23d line, for "*any limits*," read "*any limit.*"

" 29, in expression for initial velocity, for "*2 sine* $\frac{1}{2}$ *A p 8* $\sqrt{G\,o}$," read "*2 sine* $\frac{1}{2}$ *A p g* $\sqrt{G\,o}$."

" 30, in 7th line, for "*axis*," read "*axes.*"

" 33, in last line but one, for "*(n g)*" read "*(n q)*"; in last line, for "*(p g)*" read "*(p q).*"

" 34, in 7th line, for "*(p g)*" read "*(p q).*"

" 34, in 11th line, for "*n t : n g : : x : a*," read "*n′ t : n′ q′ : : x : a.*"

" 34, in 13th line, for "*(e′ P′)*" read "*(e′ p′).*"

" 36, in 3d line, for "*receiving*," read "*received.*"

" 37, in 14th line, for "*arc*," read "*area.*"

" 39, in 11th line, for "*or* $=\dfrac{a\,p\,p'}{2}$," read "*n* $=\dfrac{a\,p\,p'}{2}$."

" 40, in 6th line, for "*estimation*," read "*estimated.*"

" 42, in 1st line, for "*excussion*," read "*excursion.*"

" 43, in 5th line from bottom, for "*a = tensile strength*," read "*A = tensile strength.*"

" 44, in 6th line from bottom, for "$\dfrac{r\,2}{x\,2}$," read "$\dfrac{r^2}{x^2}$."

" 59, in 2d line after heading, for "*F. I. Shunk*," read "*F. J. Shunk.*"

" 64, in 18th line, for "*25 inches*," read "*.25 inches*"; 19th line, for "*15 inches*," read "*.15 inches.*"

" 65, in 6th line, for "*bands*," read "*barrels.*"

" 67, in next to last line, for "*axis*," read "*axes.*"

" 83, for "*Columbiad No.* 355," read "*Columbiad No.* 335."

" 84, for "*Columbiad No.* 983," read "*Columbiad No.* 335."

" 89, in 2d line, for "*295 = 300 yards*," read "*295 to 300 yards.*"

" 107, in 7th line below first table, for "*Arsenal*," read "*Arsenals.*"

" 108, in last line of table, for "*mean of last rounds*," read "*mean of last three rounds.*"

" 109, in last paragraph but one, in numbers expressive of windage, for "*18 inches*," "*3 inches*," and "*4 inches*," read "*.18 inches*," "*.3 inches*," and "*.4 inches.*"

" 111, in table, for "*H. No.* 363, *II.*" and "*H. No.* 362, *II.*" read "*H. No.* 363, *I.*," and "*H. No.* 362, *I.*"

" 137, in 13th line, for "*gun foundering*," read "*gun founding.*"

" 138, in 21st line, for "*gun foundering*," read "*gun founding.*"